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MACHINE BUILDERS HANDBOOK

By

Ye. V. Antoshin, I. L. Brinberg, et al.

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MACHINE BUILDERS HANDBOOK

By: Ye. V. Antoshin, I. L. Brinberg, et al.

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ABSTRACT: ~~This~~ The handbook contains technologies of foundry production, forging and stamping, welding production, thermal and chemical-heat treatment of metals, application of coatings on a machine part, and electrical, chemicomechanical, and ultrasonic methods of materials treatment. In each chapter the major technologies are broken down and discussed in detail. English translation; 718 pages.

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U. S. BOARD ON GEOGRAPHIC NAMES TRANSLITERATION SYSTEM

Block	Italic	Transliteration	Block	Italic	Transliteration
А а	*А а*	A, a	Р р	*Р р*	R, r
Б б	*Б б*	B, b	С с	*С с*	S, s
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П п	*П п*	P, p	Я я	*Я я*	Ya, ya

* ye initially, after vowels, and after ъ, ь; e elsewhere. When written as ё in Russian, transliterate as yë or ë. The use of diacritical marks is preferred, but such marks may be omitted when expediency dictates.

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C H A P T E R   I

TECHNOLOGY OF FOUNDRY PRODUCTION

PHYSICAL NATURE OF THE FOUNDRY PROCESS AND ITS INFLUENCE ON MANUFACTURE AND QUALITY OF CASTINGS

Shrinkage of Metal and Formation of Shrinkage Defects in Castings

During cooling of metal in the mold its volume decreases. In foundry production this decrease in volume is called shrinkage. According to the state of matter of the cooling metal or alloy its total shrinkage (the interval V_3-V_0 in Fig. 1) is divided into shrinkage in the liquid state (interval V_3-V_2), shrinkage of hardening (interval V_2-V_1) and shrinkage in the solid state (interval V_1-V_0). The amount of shrinkage of the solid metal is more conveniently determined by the change in its linear dimensions in connection with which we have the concept of linear shrinkage of metal.

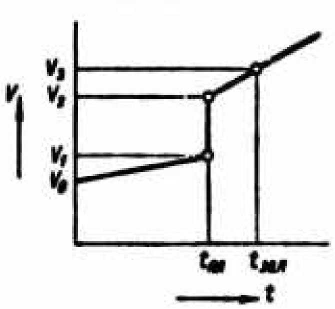


Fig. 1. Increase in volume of metal during heating and melting.

Shrinkage of liquid metal depends on the teeming temperature, and it is an indeterminant quantity. Therefore it belongs to a definite temperature interval (1^oC or 100^oC) and usually is expressed in percent. Shrinkage of hardening and

shrinkage of the solid metal (volumetric and linear) are also expressed in percent.

So that the dimensions of the cooled casting correspond to the drawing, the corresponding dimensions of the model have to be increased proportionally with respect to the linear shrinkage of the given metal or alloy. Linear shrinkage is determined by pouring a test piece of the given metal, and calculating by the formula

$$\varepsilon = \frac{l_{мод} - l_{отл}}{l_{мод}} \cdot 100\%,$$

where $l_{мод}$ is the length of the test piece pattern; $l_{омл}$ is the length of the cooled casting.

It is assumed that the dimensions of the pattern, the form prepared for it and the casting just hardened in it are identical.

Volumetric shrinkage of the hard metal is calculated by the well-known relationships for the coefficients of thermal expansion of solid bodies to be 3 times greater than linear shrinkage.

The shrinkage process to an extraordinarily great extent hampers obtaining of exact and high-quality castings. One of the complications consists in the formation inside the hardening casting of shrinkage faults in the form of all kinds of discontinuities (cavities, porosity, cracks). Appearance of these defects is connected with non-simultaneous hardening of metal in the casting. On giving off heat to the environment (material of the form), the casting starts to cool and to harden from the surface (Fig. 2a), at the same time as its internal part 2 continues to remain liquid. During subsequent cooling and hardening, the core of the casting endures more relative compression than the earlier hardening crust 1. Due to this, the continuity of the metal is disturbed and inside the casting will be formed a

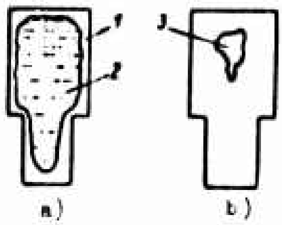


Fig. 2. Formation in a casting of a hidden shrinkage cavity: a) beginning of hardening; b) end of hardening; 1 – hard crust of metal; 2 – liquid nucleus of casting; 3 – shrinkage cavity.

vacuum vacancy 3 (Fig. 2b), called a shrinkage cavity.

The cavity shown in Fig. 2, is characteristic for section castings and is called internal or hidden. In contrast to it in ingots shrinkage of metal causes the formation of a funnel-shaped cavity (Fig. 3), which is called an external or open shrinkage cavity.

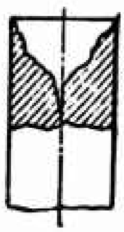


Fig. 3. Formation of an open shrinkage cavity in the casting.

The size, shape and location of shrinkage cavities are determined by the natural properties of the alloy, and also by a large set of factors affecting the process of formation of the casting. Of the natural properties, the following are most significant: amount of shrinkage of the alloy in the liquid state and during hardening the size of the temperature interval of hardening, specific gravity of the alloy and, in certain cases, the possibility of formation of different structures during hardening of the alloy. Of the other factors greatest attention is shown the following: pressure of the atmosphere, gasses given off by the metal; geometric shape and dimensions of the casting and conditions its cooling.

Shrinkage of the alloy in the liquid state and during hardening predetermines the size of the shrinkage cavity.

The size of the chrystallization temperature interval predetermines

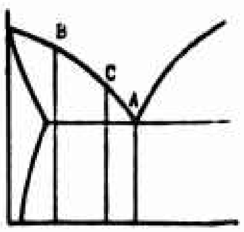


Fig. 4. Alloys in the diagram of state which form different types of shrinkage defects: A) alloy inclined to the formation of a concentrated shrinkage cavity; B) alloy inclined to the formation of scattered shrinkage porosity; C) alloy, giving a shrinkage cavity of the intermediate type.

the nature of the shrinkage defects. During hardening of a casting from a pure metal or alloy, crystallized at a constant temperature (alloy A in Fig. 4), crystals inside the casting grow in a tight dense formation (Fig 5a) and the frontal surface is continuously in contact with the liquid nucleus of the casting. This type of hardening ensures obtaining of a concentrated shrinkage cavity in the core of the casting and a tight structure of the metal in its other parts (Fig. 5d). Hardening of a casting made from an alloy with a wide temperature interval (alloy B on Fig. 4) is accompanied by the appearance of an intermediate hard-liquid layer (Fig. 5b), caused by the growth of dendritic crystals. Dendrites developed in this layer divide the liquid into separate parts, insulating them from each other and from the central, liquid nucleus of the casting. During subsequent hardening in each of these sections will be formed its own minature shrinkage cavity, as a result of which the casting turns out to be affected throughout by shrinkage porosity (Fig. 5e).

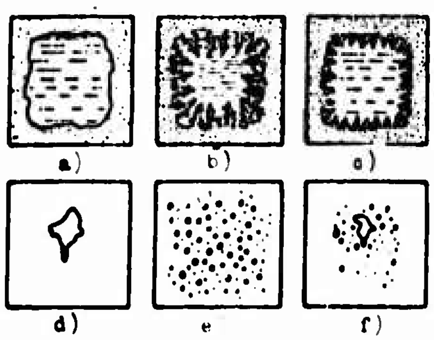


Fig. 5. Crystallization diagram and forms of shrinkage defects for alloys of varied type: a, d are pure metals, eutectic alloys, chemical compound; b, e are alloys which crystallize in a large temperature interval; c, f are alloys of intermediate type.

Alloys with small crystallization temperature intervals, for example, alloy C (Fig. 4), harden according to the intermediate diagram (Fig. 5c); the distribution of the shrinkage defects in the cavity (Fig. 5f) also turns out to be intermediate. During the development of shrinkage porosity the volume of the concentrated cavity decreases correspondingly; therefore, the porosity does not increase the total volume of the shrinkage vacancies.

<u>The specific gravity</u> of the alloy exerts significant influence on the process of forming of the casting. The greater the specific gravity, the greater the hydrostatic pressure will be in the part of the casting which is not hardening. This promotes penetration of liquid into the intercrystalline pores. Thanks to this, the number and volume of pores, especially in the lower part of the casting, decreases at the expense of an increase in the concentrated cavity. Besides this, the temperature difference promotes the appearance inside the cooling casting of convection currents, which concentrate the hottest metal (having smaller specific gravity) in the upper part of the casting (displacing the thermal center of the casting upwards), from which the shrinkage cavity is also displaced upward.

Both of these phenomena are used during development of measures to combat shrinkage defects in castings. Basic among them is risering with the help of flow gates and risers of different construction. By risering is understood compensation for the diminishing volume of liquid metal in the hardening casting (Fig. 6).

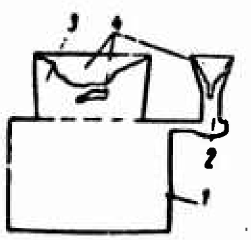


Fig. 6. Risering by a gate and risers: 1 – casting; 2 – flow gate; 3 – riser; 4 – shrinkage cavities at the flow gate and riser.

The possibility of formation of different structures depending upon conditions of hardening is observed for many alloys. The most characteristic of them is cast iron, the number and location of shrinkage defects in which to a great degree depend on the structural state of carbon. Inasmuch as the specific volume of cementite is less than the sum of the volumes of the elements which make it up (iron and carbon), during the formation of the structure of gray cast iron the volume of the shrinkage vacancies in the casting turns out to be smaller the more fully the graphitization of the carbon proceeds. In particular, for this reason white cast iron during hardening always gives greater shrinkage than gray.

For forming of shrinkage vacancies not only is the general shrinkage of hardening of an alloy, characteristic for given structural components important, but also the order, in which these components are formed from liquid phase. Thus, for instance, during hardening of cast iron crystallization of graphite and graphite eutectic occurs with expansion of volume. If these structural components were given uniformly during the entire process of hardening of cast iron, their appearance would lead only to proportional decrease in the volume of the shrinkage vacancies developed in the casting. In reality the eutectic is crystallized at the end of hardening, when in the inter-dendritic channels of the casting there remains only a small quantity of liquid. Under these conditions the expanding eutectic creates pressure in the interdendritic spaces under the effect of which the liquid may shift via capillaries to significant distances and fill in the shrinkage pores in the casting. Frequently the volume of the interdendritic pores in cast iron turns out to be insufficient for distribution of the expanding eutectic and then the rest of the

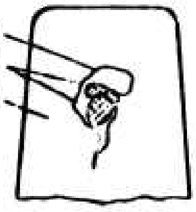


Fig. 7. Flow of expanding graphite eutectic into a shrinkage cavity: 1 – casting; 2 – shrinkage cavity; 3 – inclusion of eutectic.

liquid is squeezed into the shrinkage cavity (Fig. 7). The capacity of gray cast iron for self-packing in the process of hardening significantly facilitates the problem of obtaining high-quality castings from it.

The pressure of the atmosphere plays a significant role in the formation of shrinkage faults. In all cases, when the mold is gas-permeable, a casting hardening in it is under atmospheric pressure. A casting, hardening in a chill mold at least partially, also turns out to be under atmospheric pressure, acting through a gap, formed from shrinkage of the casting, and also from expansion and warping of the chill mold. By acting on the hardening casting with vacuum vacancies developed in it, atmospheric pressure can evoke a shift of liquid inside the hard crust and deform the latter.

On appearance of a hard crust over the entire surface of the casting, the metal in the cup of the flow gate system and in the riser continues to remain liquid. Atmospheric pressure P_0, acting on the surface of the liquid (Fig. 8), according to the law of Pascal is transmitted to its entire volume and together with the pressure P of the weight of the metal itself promotes penetration of liquid into the interdendritic spaces, where rarefaction is created as a result of the shrinkage processes. The most important role in this process almost always is played by the atmospheric pressure.

With hardening of the free surface of the metal in the riser and feeder head direct contact of the liquid nucleus of the casting

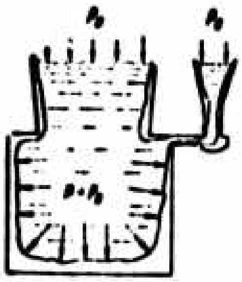


Fig. 8. Diagram of the effect of atmospheric pressure and hydrostatic pressure of the metal during risering of a hardening casting.

with the atmosphere ceases. However atmospheric pressure which deforms the hardening crust having plastic properties, continues for some time to press on the liquid core. If under the crust a shrinkage vacancy is formed, then the atmospheric pressure frequently breaks through the crust (Fig. 9a, b) and again comes in contact with the liquid, promoting airtightening of the casting.

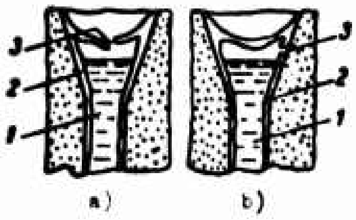


Fig. 9. Work of atmospheric pressure in pouring basin; 1 — liquid metal; 2 — hardening crust; 3 — rupture of crust under effect of atmospheric pressure.

In those cases, when on some section of the surface of the casting, the crust turns out to be weaker than in the riser cup, atmospheric pressure deforms the casting at this place, leaving a dent in its surface (Fig. 10), called in practice in foundry production a draw. Draws in castings are formed also during premature hardening of feeders and in those cases, where any part of the hardening casting turns out to be disconnected from the flow gate system and riser by neighboring parts which have hardened earlier. Formation of draws, naturally, promotes packing of the internal region of the casting, preventing the appearance and development in it of shrinkage vacancies. At the same time, draws themselves are serious defects and very frequently are a cause of writing off the castings as rejects.

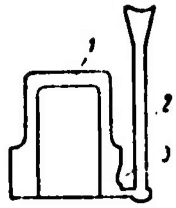


Fig. 10. Formation of a draw: 1 – casting; 2 – flow gate; 3 – draw.

Gases dissolved in a metal during weeping can in the process of cooling of the metal in a mold separate from the solution and influence the formation of shrinkage cavities. Solubility of gases in a metal decreases with lowering of pressure; therefore, in the zone of formation of a shrinkage cavity, the solution becomes saturated. Gases in the atomic state are given off at the boundaries of the shrinkage cavities and pores and occupy the space bounded by them. For this reason the internal pressure in shrinkage cavities practically always is greater than zero and in certain cases may exceed the external pressure of the atmosphere. In the internal pressure attains the sum of atmospheric pressure and the column of liquid metal above the cavity, then the volume of the latter is increased. Then the outline of the cavity becomes round which is characteristic of gas pockets. The total volume of vacancies in the metal increases, and the surplus metal is squeezed into the flow gate system or riser.

The dimensions and shape of the casting have an influence both on the size and the location of a cavity in the casting. The theoretical size of the cavity turns out to be proportional to the volume of the casting. Therefore, small castings are inclined to a significantly lesser degree toward formation of shrinkage faults. Conversely, in massive castings, shrinkage cavities and porosity appear very sharply, and coping with them is a very complicated problem.

A cavity will be formed where hardening of the casting finishes. As a rule, this place is the most massive part. If a casting has several massive nodes, then after hardening of less massive joints the thick parts harden separately from each other and in each of them will be formed a cavity (Fig. 11a). In the absence of massive nodes, shrinkage vacancies are concentrated in the central zone of the walls, located chiefly in the upper part of the casting (Fig. 11b).

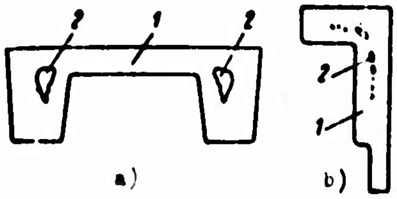


Fig. 11. Formation of shrinkage cavities in a casting; a) several thermal nodes; b) thickened part; 1 – casting; 2 – shrinkage cavity.

Any distortion of the wall evokes nonuniform cooling of it from one side or another. The convex side is cooled more intensely on the contrary, removal of heat from the concave wall of the casting is complicated. As a result, hardening of the distorted wall is finished near the concave surface; the shrinkage cavities are also shifted there (Fig. 12). For the same causes, if the walls of the casting are linked at a right angle, shrinkage cavities are arranged near the internal angle (Fig. 13). At internal angles frequently are formed shrinkage cavities, at the same time as at other places the casting hardens absolutely tight.

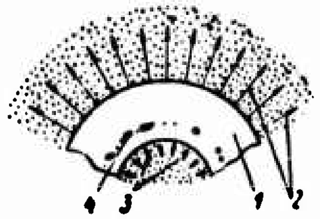


Fig. 12. Formation of shrinkage cavities in the curved wall of a casting: 1 – casting; 2 – heat radiation from the convex side of the wall; 3 – heat radiation from concave side of wall; 4 – shrinkage cavities.

If the radius of curvature of the concave wall is very small, for instance, in obtaining of a casting with a hole of small diameter (Fig. 14), then due to heating of the core, heat loss from the inside

Fig. 13. Formation of a hidden shrinkage cavity near a sharp angle of the casting: 1 — casting; 2 — shrinkage cavity.

can be completely stopped. Then the internal surface of the casting hardens last and in it will be formed an open shrinkage cavity. In this way the thermal center of the angle of a thick-walled casting (Fig. 14b) to the end of hardening shifts to the flange of the mold adjacent to the casting (the casting material at the internal angle is heated higher than the temperature of the solidus of the poured alloy), and at this place will be formed an open shrinkage cavity.

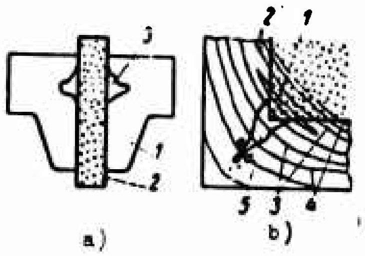


Fig. 14. Formation of an open shrinkage cavity: a) in a hole of a small diameter; 1 — casting; 2 — core; 3 — shrinkage cavity; b) at the internal angle of a thick-walled casting; 1-4 — isotherms in the body of the casting and mold; 5 — shrinkage cavity.

The condition of cooling of a casting shows up first of all in the nature of the shrinkage vacancies formed. The more intensely the casting cools, the less the extent of dendritic crystallization developed in it. The boundary between the solid and liquid phases becomes sharper, and risering of the growing crystals becomes more complete. In other words, intense cooling of a casting can serve as an artificial measure, with the help of which an alloy is inclined to dendritic crystallization (Fig. 5b); it is possible to cause hardening by the diagram characteristic for eutectic alloys (Fig. 5a). Naturally, porosity of the casting turns out to be less, and the concentrated cavity more well-developed. Namely for this reason castings, obtained in metallic molds, always turn out to be tighter by comparison with poured in sand.

The local variation in intensity of cooling of the casting plays a still greater role in foundry production. With the help of this method it is possible to regulate the process of hardening, transferring a shrinkage cavity to another less responsible place in the casting or carrying it out to the flow gate or riser. Thus, for instance, in the casting (Fig. 15a) the vertical wall in the upper part hardens earlier than the thick part located lower down, as a result of which in the thick part will be formed a shrinkage cavity. If however during molding a cast-iron refrigerator is put in the thick part then it will harden simultaneously with the thinner parts of the casting, and then the shrinkage cavity will shift to the upper part of the flow gate (Fig. 15b).

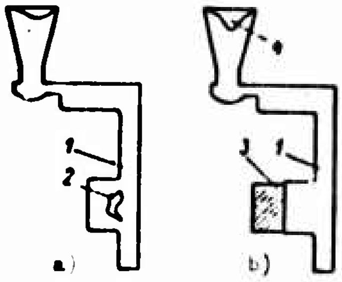


Fig. 15. Preventing of formation of a shrinkage cavity by means of installation of a refrigerator in the thick part of the casting; a) casting, hardened without refrigerator; b) casting, hardened with refrigerator; 1 – casting; 2 – shrinkage cavity; 3 – refrigerator; 4 – shrinkage cavity, transfered to the flow gate ladle.

Sometimes instead of cooling of thick parts it is more profitable to warm the thin ones which is done by using casting materials or paints with low thermal conductivity, or by local preheating of the mold before filling. Finally, an effective means of controlling the process of hardening is appropriate selection of place of feed of metal to the casting (Fig. 16).

By the set of enumerated measures, it is possible to vary within wide limits the condition of cooling of parts and nodes of the casting and to achieve simultaneous or controlled hardening of it as desired. In the first case, independently of the thickness of the walls and

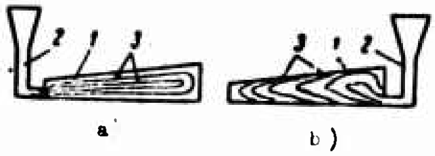


Fig. 16. Change of character of hardening of a casting depending on the place of feed of the metal; a) simultaneous hardening; b) sequential hardening; 1 – casting; 2 – flow gate; 3 – layers of consecutive hardening of the casting.

the configuration, all parts of the casting harden simultaneously; in the second case, hardening proceeds consecutively from one part of the casting to another in a given direction. During directed hardening best conditions are created for risering the casting and therefore it is a reliable means of dealing with shrinkage cavities. However a large difference of temperature occurs between separate parts of the hardening casting which predetermines formation in it of large internal stresses.

Feeding the thin part is used for castings made of gray cast iron which is inclined to a smaller extent to formation of shrinkage cavities and therefore does not need strong means of feeding. This will agree also with the requirement of obtaining iron castings with minimum stresses, inasmuch as they, as a rule, are put in operation without preliminary heat treatment. Finally, for castings made of gray cast iron feeding of metal to the thin part improves its structure; during directed hardening they would be obtained with clearly expressed anisotropy of structure and mechanical properties.

For castings made of wrought iron and steel which are very inclined formation of shrinkage faults, feeding of metal to the thick part is optinal. Internal stresses generated in this process are of no significance inasmuch as castings made of steel and wrought iron are of necessity subjected to high-temperature annealing.

Internal Stresses in Castings

General ideas about stresses. From the moment of formation of a hard crust nonuniform cooling and shrinkage of the metal cause stresses in the casting which are called temperature stresses.

In addition to temperature stresses, castings are very frequently subjected to so-called mechanical stresses, which occur in those cases, where the mold or cores put up resistance to shrinkage of the casting (Fig. 17). Resistance of the core and mold, in Fig. 17 conditionally indicated by arrows, is all the more significant the greater the shrinkage of the casting and the less yielding the mold and core. These resistances with respect to the casting are external forces, the mechanism of effect of which in principle does not differ from the effect of mechanical loads on machine and construction parts. Practically, due to different, and variable with respect to time, properties of materials of the mold, determination of the magnitude of the mechanical stresses turns out to be very complicated.

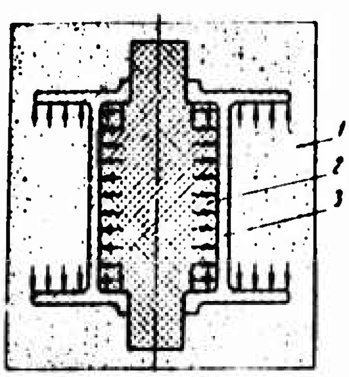


Fig. 17. Formation in the casting of mechanical stresses: 1 — mold; 2 — core; 3 — casting.

Mechanical stresses very frequently cause destruction of the casting in the mold and significantly complicate the technology of foundry production. At the same time, they are removed at the time of removal of the casting from the mold, and the influence of them on the quality of the finished product is limited to only residual strains, lowering accuracy and distorting the geometry of the castings.

Stresses in the casting can arise also due to structural or phase transitions in the alloy, taking place with a change in volume

(for instance, due to perlitic transformation in cast iron). Such stresses are called phase stresses. Phase stresses by their nature are analogous to temperature stresses inasmuch as they occur in a casting independently of the effect of external forces (mechanical resistance of the mold to shrinkage of casting). They are added to the temperature stresses and also can remain in the finished casting.

Temperature stresses are the most general case, inasmuch as they appear in every casting (for any manufacturing procedure) and are the most dangerous for poured parts working under load.

Temperature variation in cooling castings. The process of cooling of a casting, as of any heated body, possesses one characteristic peculiarity of fundamental value to the understanding of the mechanism of the effect of temperature stresses. Let us consider a casting, consisting of three parallel rods joined together by two cross pieces (Fig. 18). The thickness of the side rods 1 is less than of the middle one 2; therefore they start to cool before the middle one, and the temperature of them in the process of cooling remains lower the entire time (Fig. 19). By the extent of cooling of the casting the cooling rate of this or that part of it decreases [curves (Fig. 19) become more sloping]. If the cooling rates of rods 1 and 2 (Fig. 18) are compared, then it turns out that at the beginning of cooling, up to some point in time τ_1, rod 1 is cooled faster than rod 2; from the time τ_1 and to the end of the process rod 2 cools faster.

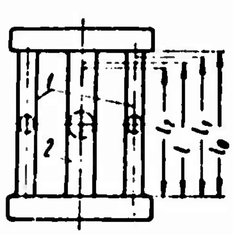


Fig. 18. Three-link lattice of stresses: 1 — thin rods; 2 — thick rod.

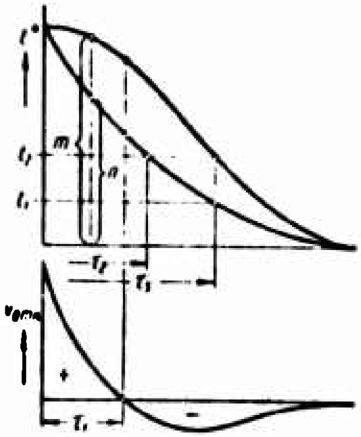


Fig. 19. Cooling in time of parts of a casting of different thickness and formation in them of temperature stresses.

This is easy to determine by the difference in the ordinates m - n (Fig. 19), which up to the time τ_1 increases, and then decreases. The variation curve for the difference in cooling rates of rods 1 and 2 is given in the lower part of Fig. 19.

Non-uniform cooling of a casting can occur not only due to the difference in thickness of its parts. Thus, the external and internal parts of a round casting (Fig. 20) are cooled nonuniformly, external and internal angles (Fig. 13), parts of a casting which are remote from the flow gate and those adjacent to it, etc. In all cases, parts of a casting which harden earlier and are cooled more intensely at the beginning of the process subsequently began to cool more slowly than the hotter parts.

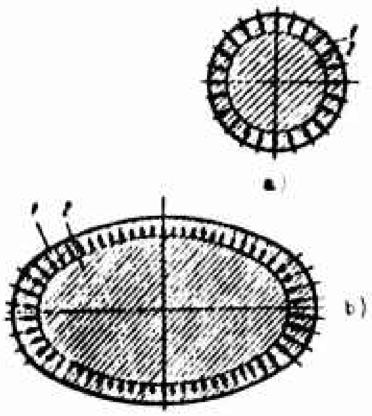


Fig. 20. Nonuniform cooling of a casting; a) cylindrical; b) elliptic: 1 — external, colder layer; 2 — hot core of the casting.

<u>Stresses in metal and formation in a casting of hot cracks</u>. One of the main dangers determined by the state of strain of a casting, is the appearance of cracks in it. Cracks depending on the temperature of the metal at which they are formed are subdivided into <u>hot</u> and <u>cold</u> cracks. Hot cracks appear chiefly at high temperatures in the process of hardening or in a casting which has

just hardened. However, under conditions suitable for this they can appear also at lower temperatures up to temperatures corresponding to transition of the metal into the elastic state. Hot cracks are characterized by uneven, "ragged" breaks in the metal following along the boundaries of crystals and the oxidized surface of the break.

All plastic bodies under the effect of forces applied to them are able to endure irreversible deformations, thanks to which stresses caused in the body by applied loads, sharply decrease. In connection with this a plastic body can be for a prolonged time in a state of strain only during continuous renewal of the external or internal forces acting on it. In a cooling casting the cause for appearance and continuous renewal of such forces is the different rate of cooling and shrinkage of its parts. Since ruptures in the casting occur only in the zones effect of tensile stresses, one should expect the formation of hot cracks both in thin and in thick parts of the casting. However, as is shown in practice, hot cracks in thin places are formed comparatively rarely. This is explained by the fact that at the beginning of cooling, when the thin part undergoes the fastest shrinkage, the thick part is still in the liquid state and does not offer it any resistance. At the time of hardening of the entire casting, the temperature of the thin part turns out to be lower, and its durability higher by comparison with the thick part. Therefore, if further shrinkage of the thin part leads to the appearance of a crack, then already at the place of juncture of it with the thick part (Fig. 21a), where the temperature is the highest, and the metal is least durable. Formation of hot cracks in a rapidly cooling thin part is also prevented by plastic deformations occurring in the hotter thick part, thanks to which the stresses in the casting

strongly decrease. Decrease of the stresses can occur also due to distortion of the geometric shape of the casting (Fig. 21b), about which more will be mentioned specifically below.

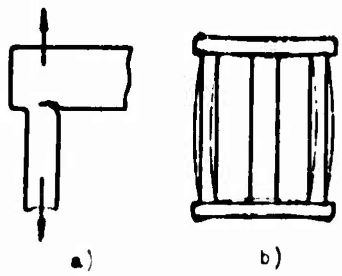


Fig. 21. Deformation and ruptures of a casting under the effect of temperature stresses; a) formation in the casting of a hot crack; b) distortion of casting.

Formation of residual stresses in castings. According to the extent of cooling of a casting, the metal loses its plastic properties and aquires elastic properties. Change of these properties occurs for every alloy in its own temperature range, in particular, for ferrous alloys in the interval 650-550°.

In contrast to stresses which are active in plastic metal the magnitude of elastic stresses does not depend on the rate of shrinkage of different parts of the casting. They are proportional to the difference in temperature between the thick and thin parts at the time of the thick part to the elastic state.

Residual stresses are practically not detested as a defect. In the presence of internal stresses a casting in use can be ruptured under loads, significantly smaller than the calculated load capacity. Cases occur where the stressed castings rupture without application of external forces to them or under insignificant strains during cleaning, transportation or machining.

Much more frequent are cases of warping of stressed castings during machining. Thus, for instance, in a cost plate (Fig. 22) the external surfaces turn out to be compressed, and the internal

Fig. 22. Deformation of a plate in the process of machining it.

region stretched. The stress field with respect to the axis a – a is located symmetrically, from which the geometric shape of the casting is not distorted. However, if by using a cutting tool we remove the surface compressed layer along the line b – b the symmetry of the stress field will be disturbed the stretched central layers will acquire the possibility of being reduced, and the compressed layers of the lower plane – to be extended, and the casting, having the stresses removed, will be bent as indicated by the fine line in Fig. 22.

Temperature deformation of castings. It was noted above that one of factors which lower the magnitude of effective stresses may be deformation of the casting the possibility of which is determined by its geometric shape and the nature of distribution of temperatures in it. The cylindrical shape of casting (Fig. 20a) is the most rigid. This is explained by the fact that the temperature field, and consequently also stresses in the volume of such a casting are distributed symmetrically. Besides, the cylindrical form of casting prevents plastic deformation of its internal part. In contrast to the lattice (Fig. 18), during intense shrinkage of the external part 1 (Fig. 20) of a cylindrical casting, the internal part 2 cannot be plastically deformed, inasmuch as the metal is incompressible. In the second period of cooling, when the internal part is compressed more rapidly, deformation of the external part also practically is impossible, since it has the most rigid form of a cylindrical arch; moreover, due to the lower temperature its mechanical properties are greater than those of the central part of the casting. Due to this

the big cylindrical castings are much disposed to formation of external and internal cracks and therefore, in spite of simplest geometric shape they belong to the category of most difficult to produce.

An ingot of any other geometric shape turns out to be less rigid. Thus, for instance, if the cross section of an ingot is elliptical (Fig. 20b), then the faster cooling external layer 1 deforms the internal part 2, compressing it along the great axis of the ellipse. The volume and area of the cross section of the internal part, of course, will remain constant, however, the perimeter of the ellipse, approaching a circle, will continuously be reduced. At the same time the external stretched layer 1 will be shortened; thus, the stresses are eliminated.

For section castings due to more well-developed geometric form the possibilities for temperature deformations are significantly greater. Nonetheless in them nodes are encountered, dealing with the cracks in which constitutes one of the basic difficulties in the technology of foundry production.

The case of temperature deformation of a casting of the beam type with asymmetric distribution of temperatures during cooling in the mold, is interesting. The casting is irreversibly deformed (bent) with convexity in the direction of intense cooling (Fig. 23). This occurs because the thick side of the casting is cooled more slowly and hardens later than the thin side, in consequence of which at the time of total hardening of the casting it is at the temperature of the solidus line, whereas the thin part by then has been cooled to a somewhat lower temperature. During subsequent shrinkage of the casting the thicker (hotter) side of it, according to the law of

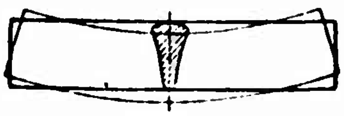


Fig. 23. Temperature bend of a beam of nonuniform cross section.

physics, is shortened more than the thin side which leads to deformation.

The physical problem which have been considered are the basis of the majority of the rules presented below for construction of cost parts. It is characteristic that dealing with residual stresses (which by nature are temperature stresses) is impossible by means of increasing the durability of the material of the casting. Since stresses of one sign in all cases are balanced by stresses of the other sign in the volume of the same casting, its resistance to formation of cracks turns out to be independent of the durability of the material and is determined exclusively by its plastic properties. Increase in the durability of the metal for the purpose of strengthening a section of the casting, under the effect of stretching stresses calls for the same strengthening as of its compressed parts. Theoretically this will lead only to proportional increase in the state of strain of system as a whole from which the reserve of durability of the weak place will not be changed. Practically such a measure most frequently leads to increase in the number of cracks, since increase in the durability of the metal in most cases is accompanied by a drop in its plastic properties.

BASIC PRINCIPLES OF CONSTRUCTION OF CAST PARTS

Cast parts must be designed in such a manner so that they are technologically feasible in production, ensure least expenditures of labor and material, and also allow maximum mechanization and automation of their manufacturing process.

In construction of these parts we must also consider: standardization, unification, normalization, convenience of operation,

transportableness for the railroad.

Design of the Outside Surface of a Casting

Surfaces of castings should come as close as possible to the plane or surface of a solid of revolution. Their external form must be simplified as much as possible in order to ensure molding and to ensure easy extraction of the model from the form. A model is not required to have among its elements so-called shadow zones (Fig. 24), removal of which excludes use on the models of removable parts, additional cores, core prints, which lower the accuracy of manufacture of casting. A casting should have as little as possible curvilinear shape (Fig. 25).

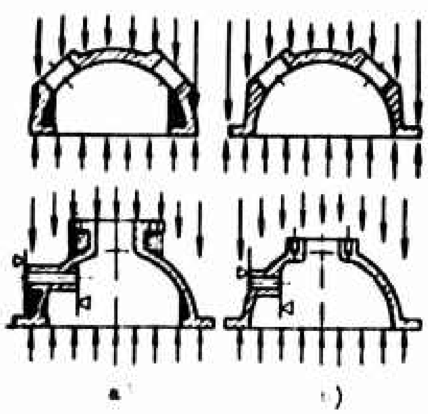


Fig. 24. Poured construction: a) shadow zones; b) without shadow zones.

Elements of construction with respect to external shape must be arranged in one plane (Fig. 26).

Parts, having elements which protrude sharply, are fast worn out, or are significantly complicated with regard to casting technology must be dismembered and then joined by welding or bolts (Fig. 27). Sometimes, conversely, it turns out to be expedient to unite separate nodes into a single cast part (Fig. 28a). Such variation allows significant lowering of the labor-consumption of the processes of manufacture and an increase in the operating characteristics of construction.

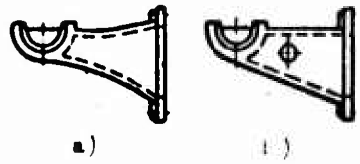


Fig. 25. Outlines of bracket pattern: a) curvilinear; b) rectilinear (straight).

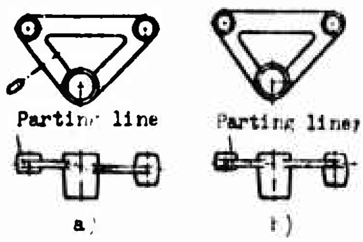


Fig. 26. Construction of a lever; a) with arms in different planes; b) modified with arms in one plane.

The upper (on filling) extended planes of the part must be given certain curvature to intersect the lower plane by ribs (Fig. 29b) or to make the upper surface rippled (Fig. 29d). Well-developed planes serve as screens of radiant heat during pouring. Reefs, ribs and slopes of the planes protect the cast part from formation of rejects in the form of shrinkage cavities.

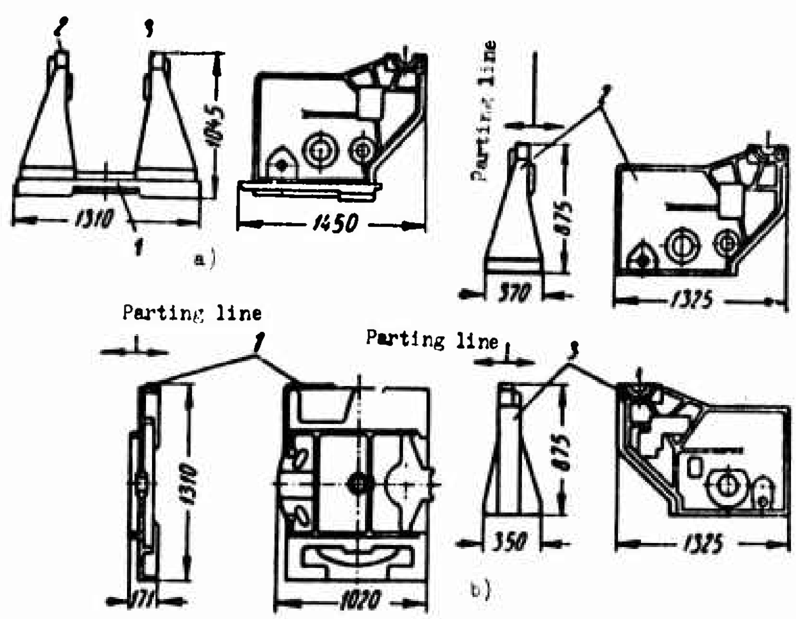


Fig. 27. Cast construction: a) integral casting; b) dismembered into three parts 1, 2 and 3.

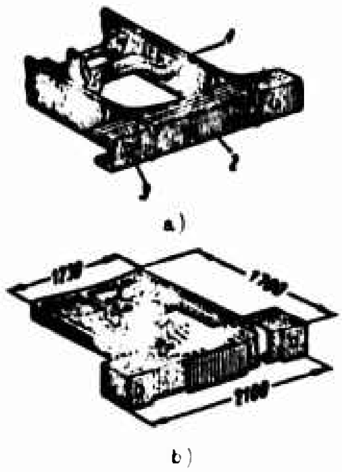


Fig. 28. Box: a) welded, united from three parts 1, 2 and 3; b) integral cast.

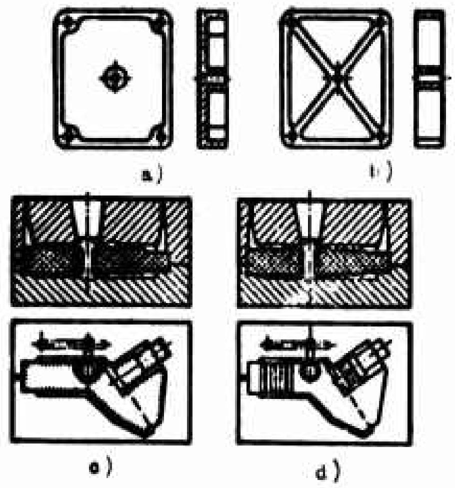


Fig. 29. Cast construction: a and c) not straight; b and d) straightened with ribs and rippled surface.

In a cast part one must not permit bilateral machining, especially of those surfaces on which the biggest power loads (Fig. 30a sections A) will be applied.

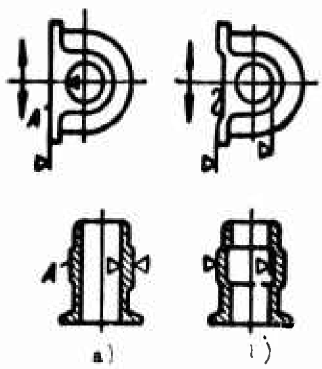


Fig. 30. Cast constructions: a) bilateral machining in the danger zone; b) one-sided treatment.

Among the basic requirements of construction one should also have rational arrangement (Fig. 31b) that lowers the dimension of flasks, the expenditure of molding-core materials, capacity of the molding machines and expenditure of operating time.

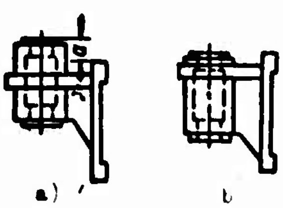


Fig. 31. Grouping of a part: a) irrational; b) rational.

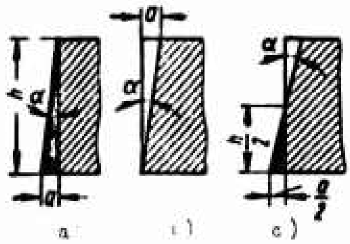


Fig. 32. Molding slopes; a) increase in thickness of the wall (slope in the "plus" direction); b) decrease in thickness of wall (slope in the "minus" direction); c) simultaneous decrease and increase in the thickness of the wall (average slope).

All surfaces of poured constructions which are arranged during perpendicular molding of the parting line of the pattern, have to have slopes (All-Union Government Standard 3212-57) for free extraction of the model from the mold and of the core from the box. Mold slopes can be made in three ways (Fig. 32). The magnitude of the slope depends on the height (length) of the wall and is indicated in degrees (minutes). During selection of the slope according to the height of the wall it is necessary to take into account the method of molding (manual or machine), the material of the model (metallic or wooden).

If the vertical walls of the casting are machined or its thickness is less than 8 mm, the slope is anticipated, as a rule, "in the plus direction;" for a wall thickness 8-12 mm. — "plus-minus," for thickness greater than 12 mm, and height of wall less than 100 mm, "in the minus direction" and for a height of wall greater than 100 mm — "plus-minus."

Different methods of casting provide different surface finish (All-Union Government Standard 2789-61) on the cast parts:

Accuracy class	Finish class	Casting procedure
I	1, 2, 3	in sand molds
II	4, 5, 6	in cores and metallic molds
III	7, 8, 9	by wax pattern

During construction of the surface of castings one must pay special attention to the base planes (the conditional plane, from which dimensions are measured during layout of the pattern and casting, it is a support during machining). It is desirable that the cast construction have the same base planes for manufacture and testing of the models, for casting and machining. The base plane on long castings should be formed at the expense of bosses, paying, flanges, which during warping of the casting will not cause great distortion of it. It is very important that the base planes have minimum dimensions and be located at equal distance from all points of the surface. This decreases the allowance on each dimension. During necessity the base plane must be purposely displaced, where it is necessary to reach minimum allowances on dimensions. The base surface does not have to be intersected by the parting line of the mold.

For processed cast parts one must foresee the allowances on machining. In the selection of the allowance it is necessary to consider the brand of alloy, the dimension of the castings, disposition in the mold of the processed planes. The magnitudes of the allowances on treatment and allowed deflections by weight for iron castings are shown in All-Union Government Standard 1855-55 and for steel castings in All-Union Government Standard 2009-55 (Tables 1 and 2).

Accuracy class I extends to castings made in mass production during machine molding by metallic patterns;

Accuracy class II — to castings of serial production during machine molding by wooden patterns;

Accuracy class III — to castings of individual production during manual molding by wooden patterns.

Table 1. Allowed Deflections by Dimensions of Castings from Gray Cast Iron and Steel in mm (±)

The biggest dimension of the casting in mm.	Nominal dimesion in mm.						
	Up to 50	Above 50	120—260	260—500	500—800	800—1250	1250—2000
I class of accuracy							
Up to 120	0.2	0.3	—	—	—	—	—
120—260	0.3	0.4	0.6	—	—	—	—
260—500	0.4	0.6	0.8	1.0	—	—	—
500—1250	0.6	0.8	1.0	1.2	1.4	1.6	—
1250—3150	0.8	1.0	1.2	0.4	1.6	2.0	2.5
3150—6000	1.0	1.2	1.5	1.8	2.0	2.5	3.0
II class accuracy							
Up to 260	0.5	0.8	1.0	—	—	—	—
260—500	0.8	1.0	1.2	1.5	—	—	—
500—1250	1.0	1.2	1.5	2.0	2.5	3.0	—
1250—3150	1.2	1.5	2.0	2.5	3.0	4.0	5.0
3150—6300	1.5	1.8	2.2	3.0	4.0	5.0	6.0
III class accuracy							
Up to 500	1.0	1.5	2.0	2.5	—	—	—
500—1250	1.2	1.8	2.2	3.0	4.0	5.0	—
1250—3150	1.5	2.0	2.5	3.5	5.0	6.0	7.0
3150—6300	1.8	2.2	3.0	4.0	5.5	6.5	8.0
6300—10 000	2.0	2.5	3.5	4.5	6.0	7.5	9.0

Table 2. Allowed Deflections by Weight of Casting from Gray Cast Iron and Steel in % (by All-Union Government Standard 1855-55 and 2009-55)

Nominal weight of casting in kg.	Class of accuracy		
	I	II	III
Up to 80	5	7	8
To 80 from 500	4	6	7
Over 500	3	5	6

Table 3. Allowed Deflections by Dimensions of Casting from Wrought Iron in mm (±)

Dimension of casting in mm.	Class of accuracy	
	I	II
Up to 100	0.5	1.5
101—250	1.0	2.0
251—400	1.0	2.5
401—650	1.5	3.0
651—1000	1.5	3.5
1001—1600	1.5	4.0

Table 4. Allowed Deflections by Dimensions of Castings from Copper Alloys in mm (±)

Dimension of casting in mm.	Class of accuracy	
	I	II
Up to 150	0.5	1.0
151—250	0.5	1.5
251—600	1.0	1.5

Table 5. Allowed Deviations by Weight of Castings from Wrought Iron in %

Weight of casting in kg.	Class of accuracy			
	I		II	
	+	-	+	-
Up to 0.1	6	6	11	10
0.2—0.5	6	5	9	9
0.6—3.0	5	5	8	8
3.1—12	5	4	7	7
12.1—50	4	4	6	6
Above 50	4	3	5	5

For castings from wrought iron and nonferrous alloys it is recommended to use standards developed TsNIITMASh* (Tables 3-6).

Dimensions of losses, plates steps and transition faces which shape external contour are recommended to be selected depending upon given dimensions of the cast construction, which are found by

*Translation Editor Note: ЦНИИТМАШ: Central Scientific Research Institute of Technology and Machine Technology.

Table 6. Allowed Deflections by Weight of Castings from Copper Alloys in %

Weight of casting in kg.	Class of accuracy			
	I		II	
	+	–	+	–
Up to 0.1	6	5	11	10
0.1–0.2	5	5	10	9
0.2–0.4	5	4	9	8
0.4–0.8	4	4	8	8
0.8–1.5	4	3	8	7
1.5–3.0	3	3	7	6
Above 3	3	2	6	5

Table 7. Recommended Dimensions of Bosses, Plates and Transition Faces

Given dimension in meters	Height of plate and bosses above untreated surface in mm (not more)	Height of step on treated surface in mm (not less)	Height of transition face during transition of treated surface to untreated in mm (not less)
0.5	10	12	5
2.0	15	18	8
4.5	20	25	12
8.5	30	40	18
13	40	50	22

the formula

$$N = \frac{2l + b + h}{3}\ \text{м},$$

where l is length; b is width; h is height of casting in meters.

Magnitudes of the elements shown are given in Table 7.

Between the diameter D of the bosses and diameter d of the core hole there should be the following relationship:

$$d \leqslant 40 \text{ when } D \geqslant 2d;$$
$$d \leqslant 50 \div 80 \text{ when } D \geqslant 1{,}5d;$$
$$d \leqslant 80 \text{ when } D \geqslant d + (4 \div 6)\delta \text{ (when } \delta >$$
$$> 15\,\text{мм}) \text{ и } D \geqslant d + (4 \div 8)\delta \text{ (when } \delta < 15\,\text{мм});$$

δ is the thickness of the wall of the cast construction.

If the bosses, plates and steps are in one plane and are smooth out the massiveness located close together, then it follows to unite them and created massiveness created (to decrease local accumulation of metal).

Construction of Walls

Selection of minimum thickness of wall. On selection of the minimum thickness of walls of a cast construction it is necessary to consider their purpose and also dimension, weight and method of

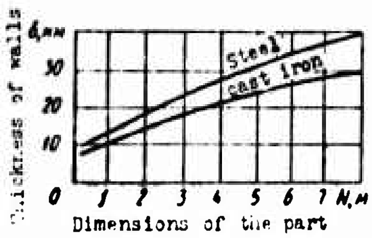


Fig. 33. Definition of minimum thickness of wall.

manufacture of the part. On casting in sand molds the thickness of the walls of cast-iron, chiefly of big castings can be found by the diagram in Fig. 33 depending on the given dimension of the castings N.

The thickness of walls of small and average castings made of cast iron, steel and nonferrous metals can be determined by the formula

$$\delta = \frac{L}{100} + 4 \text{ mm},$$

where L is the biggest dimension of the cast part in mm, or by Table 8.

Table 8. Minimum Thickness of Walls for Different Alloys in mm

Material	The biggest dimension of the part in mm		
	Up to 500	Up to 1500	Above 1500
Cast iron gray. . .	6	10	15
Malleable cast iron	5	8	—
Steel.	7	12	20
Bronze	3	6	—

Construction of wall couplings.

On joining walls it is necessary to smooth out their thickness, in order to remove internal stresses and shrinkage cavities. Uniformity of thickness of walls and allowed accumulation of metal in their linkages may be determined by rule of inscribed circumference. It is necessary to observe condition $d \leq 1.5\ \delta$, where d is the diameter of the inscribed circumference, δ is the minimum thickness of the wall (Fig. 34).

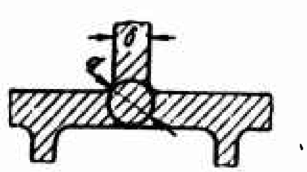


Fig. 34. Application of method of inscribed circumferences.

On joining of walls, differing in thickness by 2 times and more, one should use a cone linkage.

For cast iron and nonferrous metals one should observe the condition (Fig. 35) $l \geq 4$

(a - b), and for steel $l \geq 5$ (a - b).

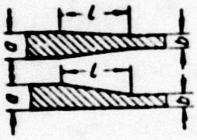


Fig. 35. Gradual change of sections.

The thickness of walls, located inside the casting, in view of their delayed cooling one should select approximately 20% less than for the external walls. Allowed deviation in thickness of walls and ribs have to correspond to All-Union Government Standard 1855-55 and 2009-55 (Table 9).

Table 9. Allowed Deviations in Thickness of Unprocessed Walls and Ribs in mm (±)

The biggest dimensional dimension of the casting in mm	Thickness of wall or rib in mm	Class of accuracy I		II		III	
		Cast iron	Steel	Cast iron	Steel	Cast iron	Steel
Up to 500	6—10	0,3	0,5	0,5	0,8	1.0	1.0
	10—18	0,5	0,8	0,8	1.0	1.6	1.5
	18—30	0,8	1.0	1.0	1.0	1.6	1.5
500—1250	10—18	0,5	1.0	1.2	1.5	1.5	2.0
	18—30	0,8	1.0	1.5	1.5	2.0	2.0
	30—50	1.0	1.2	1.8	2.0	2.0	2.5
1250—2500	18—30	0,5	1.5	1.2	2.0	1.5	2.5
	30—50	0,8	1.5	1.5	2.5	2.0	3.0
	50—80	1.0	2.0	1.8	3.0	2.0	3.5

For wall joints it is necessary to avoid acute angles, in which as a result of fast cooling stresses and mircrocracks occur. Fillets must be selected so that they ensure smooth transition and remove local accumulation of metal. All-Union Government Standard 2716-44 recommends the following series of radii of internal fillets: 1, 2, 3, 5, 8, 10, 15, 20, 25, 30, 40 mm. The radii of fillets should be taken from 1/5 to 1/3 of the average-arithmetical thickness of the joined walls. For alloys with increased shrinkage (nonferrous alloys, malleable, gray steel, alloy manganous, chrome-nickel cast iron) radii of fillets are recommended from Table 10.

In one casting it is necessary to have a minimum number of radii; desirably to reduce them to one radius of all parts and in the drawing to be limited by a note, for instance: "foundry radii of internal angles R6."

For avoiding of local thickenings and creation of smooth transitions the angular joints for the relationship of thicknesses

Table 10. Radii of Internal Fillets, Determined by Thicknesses of Conjugate Walls, in mm

$\frac{a+b}{2}$	r	$\frac{a+b}{2}$	r
Up to 12	6	45–60	25
12–16	8	60–80	30
16–20	10	80–110	35
20–27	12	110–150	40
27–35	15	150–200	50
36–45	20	—	—

a and b — thicknesses of conjugate walls, r — radius of internal fillets.

of walls $A/a \leq 2$ are made with external radius R equal to the thickness of A wall, and with internal radius r of curvature equal to 1/6 to 1/3 average-arithmetical thickness of the walls, i.e., $r = 1/6\,[(A + a)/2]$ to $1/3\,[(A + a)/2]$ (Fig. 36a). For greater difference in thickness of walls construction of transitions according to Fig. 36b, where $c \approx \sqrt{A - a}$; $a + C \leq A$; $h \geq 4c$. For a steel casting $h \geq 5c$.

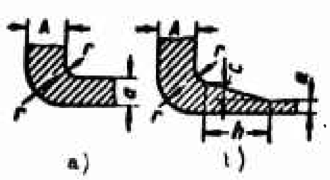


Fig. 36. Angular joint of walls; a) for a ratio of thicknesses less than two; b) for a ratio of thicknesses of more than two.

In Fig. 37 the following variants of permissible (on the right) and recommended (on the left) joints of two walls (Table 11) are given.

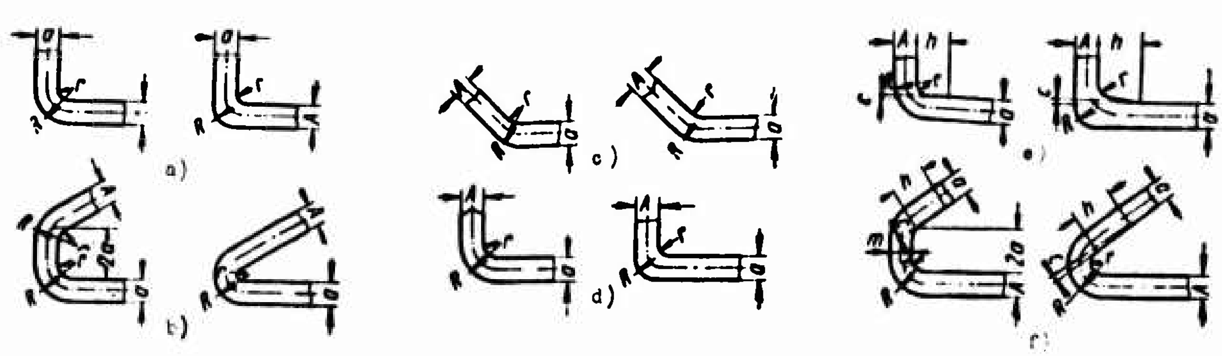


Fig. 37. Construction of joints of two walls: recommended — on the left, permissible — on the right.

Radius R in permissible diagrams (Fig. 37a, c, d, e) is assumed by constructive considerations; h for cast iron is chosen

Table 11. Recommended Parameters of the Juncture of Two Walls

Parameters of linkage	Form of linkage (Fig. 37)					
	a	b	c	d	e	f
	Dimension of linkage					
$A:a$	1	1	1	>1.25	1.25	>1.25
Angle of intersection	75–105	>75	>105	75–105	75–105	<75
R in mm	$r+a$	$r+a$	$r+a$	$r+a$	$r+a+c$	$r+m=r+a+c$

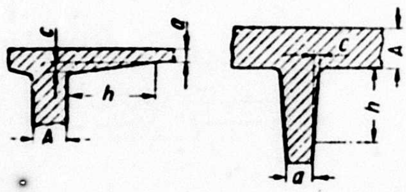
approximately equal to 4c, for steel ~5c; the value of c is chosen by the relationships:

$A:a$	>2.5	1.8–2.5	1.25–1.8	<1.25
c	$0.7A-a$	$0.8A-a$	$A-a$	–

Linkage of three walls may be constructed according to the diagrams of Figs. 38 or 39. The value of h (Fig. 39) is assumed for cast iron $h \approx 8c$ and for steel $h \approx 10c$. The value of c is chosen by the relationships:

$A:a$	>2.5	1.8–2.5	1.25–1.8	>1.25
c	$\frac{0.7A-a}{2}$	$\frac{0.8A-a}{2}$	$\frac{A-a}{2}$	–

In castings made from aluminum alloys at intersections of two and three walls the relationships of construction elements, shown in Fig. 40 are recommended where $h = 2(A + a)$; $h_1 = 2.5(A + b)$; $c = 0.75A$; $d = r = 0.5A + a$; $l = 0.5(A + a)$.



a) b)

Fig. 38. Juncture of three walls: a) for $c \approx 3\sqrt{A - a}$; $a + c \leq A$; $h \geq 4c$ for cast iron and $h \geq 5c$ for steel; b) for $c \approx 1.5\sqrt{A - a}$; $a + 2c \leq A$; $h \geq 8c$ for cast iron and $h \geq 10c$ for steel.

Rounding of walls at junctures of surfaces depends on the size of the latter and the angles of juncture (Table 12). For this (Fig. 41) the initial size of the surface serves as the dimension P, perpendicular to the generating cylindrical surface of rounding.

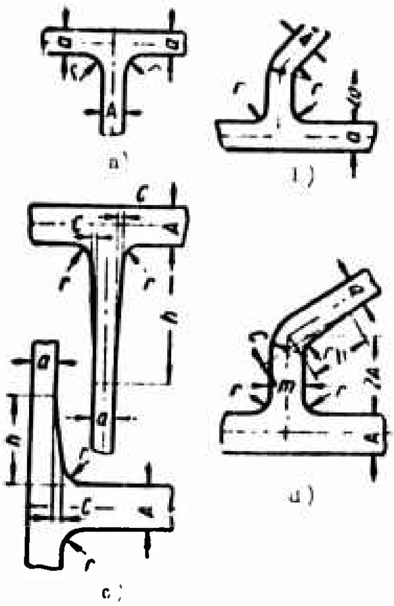


Fig. 39. Diagrams of linkages of three walls: a) when $A \approx 1.25\,a$, $\alpha = 75$-105°; b) for $A \approx 1.25\,a$ and $\alpha = 75^{\circ}$; c) for $A > 1.25\,a$ and $\alpha = 75$ to 105°; d) $A > 1.25\,a$; $\alpha = 75^{\circ}$; $R = r + m$; $m = a + c$.

Table 12. Magnitudes of Radii of Rounding of Linked Surfaces

Dimensions P, P_1, P_2, in mm	Angle of linkage α, α_1, α_2°: Up to 50	50—75	75—105	105—135	135—165	Above 165
	Radii R, R_1 and R_2 of rounding of linked surfaces in mm					
Up to 25	2	2	2	4	6	8
26—50	2	4	4	6	10	16
51—150	4	4	6	8	16	25
151—250	4	6	8	12	20	30
251—400	6	8	10	16	25	40
401—600	6	8	12	20	30	50
601—1000	8	12	16	25	40	60
1001—1600	10	16	20	30	50	80
1601—2500	12	20	25	40	60	100
Above 2500	16	25	30	50	80	120

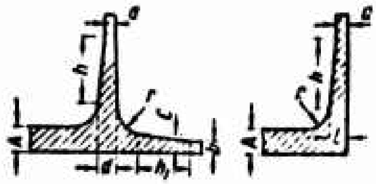
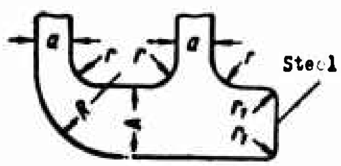


Fig. 40. Construction of joints in aluminum alloy castings.

In steel castings the radii given in Table 13 are used.

Table 13. Radii of Rounding in Steel Castings

$$R = r + \frac{A + a}{2}\ мм;\ r \geq 3\ мм.$$



Ratio of thickness of linked walls A:a	Radius r for minimum thickness of wall a in mm: До 6	Св 6 до 10	Св. 10 до 15	Св. 15 до 20	Св. 20 до 25	Св. 25 до 35	Св. 35 до 45	Св. 45 до 60	Св. 60 до 80	Св. 80 до 100
Above 1 up to 2	5	8	10	12	15	20	25	30	40	50
Above 2 up to 3	6	10	12	15	20	25	30	40	50	—
Above 3. . . .	10	12	15	20	25	30	40	50	—	—

До – up to; Св – above.

On construction of cast-iron parts one should give such form to the cross sections that will ensure free shrinkage of the

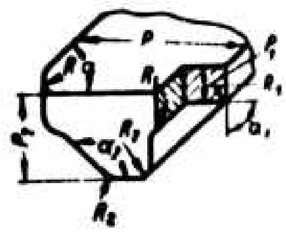


Fig. 41. Diagram of rounding of surfaces of walls.

casting (Fig. 42). Sections with mechanical and thermal braking of shrinkage should not be used, since in this case rejects due to warping and cracks are increased.

In the construction of walls it is necessary to consider location of them during pouring (Fig. 43). It is necessary to avoid large horizontal planes, turned upwards during risering since in them gases, slag and other nonmetallic impurities can reside which are formed in the mold and given off from the metal. Diagrams (Fig. 43b), furthermore, ensure localization of internal stresses and remove rejects due to cracks as a result of free deformation of them during cooling.

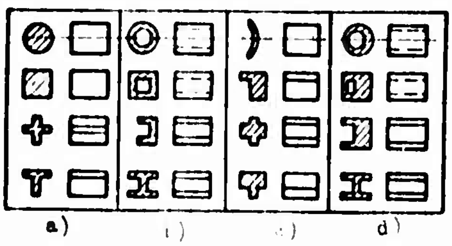


Fig. 42. Diagram of construction of castings: a) with free shrinkage; b) with mechanical braking of shrinkage; c) with thermal braking of shrinkage; d) with mechanical and thermal braking of shrinkage.

Construction of cast parts should correspond with simultaneous or consecutive (directed) hardening of the casting. In the first case the greatest uniformity of cross section is desirable, in the second, gradual build-up of massiveness of walls in assumed direction of hardening (Figs. 44 and 45).

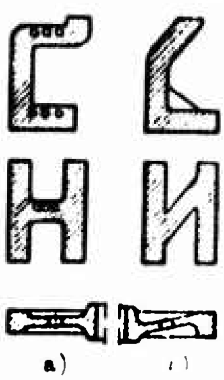


Fig. 43. Diagram of cast constructions a) nonstraightened — not ensuring surfacing of gases and nonmetallic impurities; b) straight.

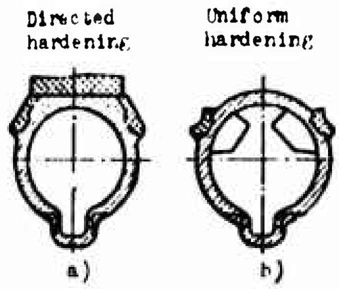


Fig. 44. Cast construction; a) with riser and directed hardening of metal from bottom to top; b) with refrigerators, uniform hardening.

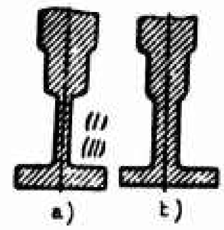


Fig. 45. Construction of walls; a) with unimpregnated zone I and presence of porosity in zone II; b) straight — with gradual thickening of wall upwards.

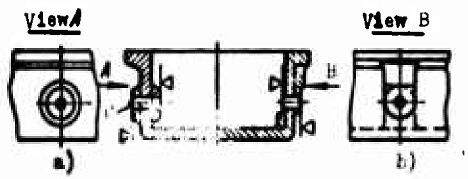


Fig. 46. Cast construction; a) accumulation of metal in node B; b) protrusion removed.

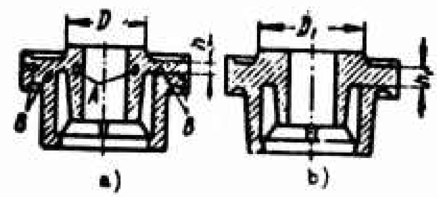


Fig. 47. Cast construction; a) accumulation of metal at nodes A and B; b) accumulation of metal removed.

In cast parts even with relatively equivalent cross sections of walls usually there are knots of accumulation of metal (Fig. 46B), or the latter are divided by thin crosspieces (Fig. 47B and A). Insufficient risering of such nodes, especially during casting of alloys with heightened shrinkage, leads to formation of porosity of shrinkage origin. One should not allow local accumulations in wall joints.

Construction of Ribs

The thickness of the ribs which shapes the external contour does not have to exceed 0.8 of the least thickness of the wall they

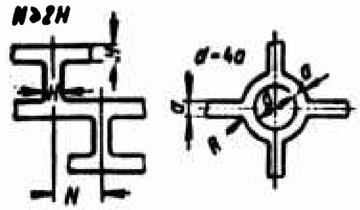
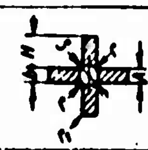
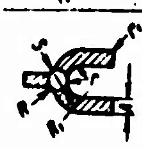
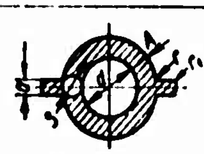
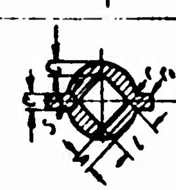


Fig. 48. Diagrams of forming of ribs and partitions.

adjoin; and the thickness of ribs of internal cavity, — 0.5-0.6 of the thickness of the wall. The weight of the ribs need not be more than 5 times the thickness of the wall. Is recommended to use crisscross or annular crossing of ribs and partitions (Fig. 48).

In Table 14 are given diagrams of crosspieces with ribs and the ratios of dimensions, which are used in practice.

Table 14. Recommended Ratios of Dimensions of Castings with Ribs

Cross section	Sketch	H	a	b	c	R_1	r	r_1	s
Cross-like		2		0.6	—	—	0.3	0.25	1.25
Forked		—	—	—	—	1.5	0.5	0.25	1.25
Annular with ribs		—	0.8	—	—	—	0.5	0.25	1.75
The same with square section		—	1.0	—	0.5	—	0.25	0.25	1.25

Note: Dimensions are given in fractions of the dimension A.

Dimensions R, d and b are selected from construct considerations. The rib of rigidity must be situated perpendicular to the parting line of the mold and core and rod box (for simplification of molding) and symmetrically (for equal distribution of internal stresses); for decrease of warping in joints one should anticipate core holes.

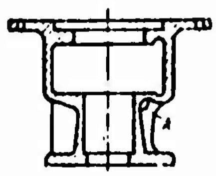


Fig. 49. Construction of ribs of rigidity: left half – not straight, straight outline of rib; right – straight.

The outer edge of the ribs must be shaped in a curve for easing of deformation during shrinkage of the metal (Fig. 49, right half with hole A).

Construction of Internal Casting Planes and Holes

Formation of almost all varieties of casting porosity is connected with the use of sand core processes of manufacture of which is labor-consuming, requires the use of expensive binders, prolonged drying, cores which are difficult to remove from the casting. Therefore, they must be replaced by protruding masses – from "blocks."

Replacement of the cores is possible for cavities located in the lower half-mold when $H \leq D$, where H is depth, D is width of cavity (Fig. 50); for cavities located in the upper half mold, when $h \leq 0.3\ d$. Furthermore, it is recommended that one observe the relationship $H < N$ and $h < n$; i.e., not one of the "blocks" need protrude beyond the parting line cavity.

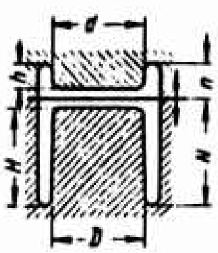


Fig. 50. Dimensions of internal cavities, formed by the protruding masses of the mold.

An internal cavity must have outlets, necessary for formation in the cores of support marks. These holes must be made quite well-developed, and as far as possible they have to be a continuation of the cavity. With well-developed sign holes or windows is ensured reliable bracing of cores in the mold and knockout of them from the casting is facilitated. In the presence in the cavity of only one output window (Fig. 51a) and one sign it is necessary for reliable support of the core to use metallic chaplets which worsen the quality of the

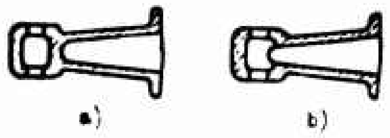


Fig. 51.

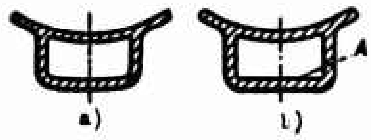


Fig. 52.

Fig. 51. Cast arm: a) with dismembered core and chaplet; b) without dismemberment of core.

Fig. 52. Construction of internal cavity: a) is not technological; b) is technologic with a well-developed straight line by plane A.

castings and disturb continuity of the walls. It is recommended that under the chaplet one creates a local thickening of the wall (if the thickness is insufficient), so that the liquid metal fuse the chaplet. If the length of the core exceeds its diameter by more than 2 times, it is necessary to make the cavity with two outlets or windows. It is necessary to remember that the upper core marks easily carry off gases at the time of filling. For blind cavities it is necessary to anticipate holes in the part which are closed subsequently by plugs. During construction of cavities it is necessary to observe the technological condition. For a large quantity of rods one should unify them, anticipate one flat side, so that one avoid deformation of the core during drying. This will allow use of the machine method for manufacture (Fig. 52b) of them.

The cross section of cavity should be not less than one and a half thicknesses of the wall, so that cores not be broken during pressure on the liquid metal and it be allowed to strengthen their quite rigid frames (Fig. 53b).

Holes in the casting need not be filled in, if the diameters of them do not exceed (in mm):

for mass production 20
for serial production 30
for individual production 50

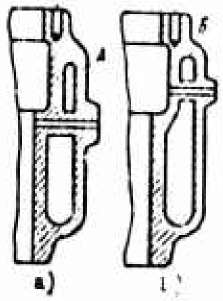


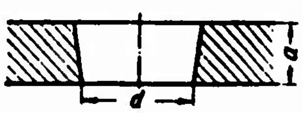
Fig. 53. Cast cylinder; a) with narrow cavity A; b) with expanded cavity B.

In light weight parts with thin walls, like parts of agricultural and textile machine building, in individual cases it is possible to obtain holes in the casting of significantly smaller diameters (Table 15).

Windows and holes of increased dimensions one should be reinforced by flanging (Fig. 54), which prevents occurence of hot and cold cracks.

Cast construction does not have to have thin grooves and flanges, formed by thin flanges and cross pieces of the mold. Thin protruding parts of the mold can be washed by the metal in process of filling which will cause rejects for sand cavities and deposits.

Table 15. Holes Made in Casting During Manufacture of Small Parts



a	d	a	d
4–6	8	14–16	16
6–8	10	16–18	20
8–10	12	18–20	28
10–12	14		
12–14			
Pitch of holes 1:10.			

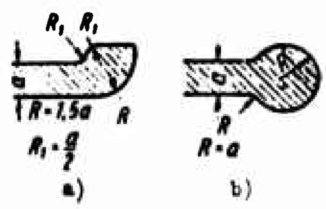


Fig. 54. Diagrams of flanging for cast parts: a) double-walled; b) monowall.

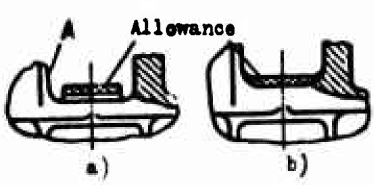


Fig. 55. Construction of poured cavities: a) untechnologic construction; b) technologic construction.

The presence of a narrow recession A (Fig. 55a) may cause reject of the part. If it is not possible to expand the groove, then one must make the boss in the form of Fig. 55b.

It is necessary to avoid grooves for leaving of the cutting tool. The desire of the designer

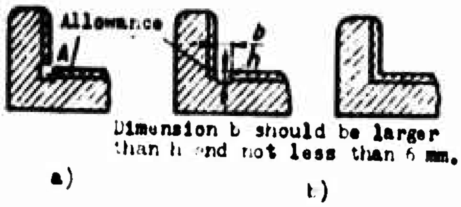


Fig. 56. Construction of a cast part: a) with groove A, is not recommended; b) recommended construction shapings.

to create free exit for the tool leads sometimes to incorrect construction with an untechnologic cast groove A (Fig. 56a). In this case it is more profitable to avoid the groove, selecting one of the variants, shown on Fig. 56b.

CAST-IRON AND STEEL CASTING

Basic Methods of Obtaining Castings

For the manufacture of castings different technological methods (Table 16) are used during the selection of which it is possible to be guided by Table 17.

Depending upon the conditions of the casting housing and dimensions of the casting the following methods of molding are used: in soil, in two (Fig. 57c) and several flasks manually, in molding machines, by metallic model plates (Fig. 57b). Flow gate system is brought in from above, from the side and from beneath (Fig. 57c and d).

Small and average molds during packing on machines are prepared damp. According to the extent of complication of the molds and increase in their dimensions the use of green sand molding will be increased. In mass and large-scale serial production half molds and chill molds (Fig. 57d) are used.

It is necessary to consider that steel has heightened shrinkage — linear 2.0% and volume 6%, and also less fluidity than cast iron.

During construction of a casting it is necessary to anticipate position of the part during filling (Table 18) and the parting line of the mold (Table 19).

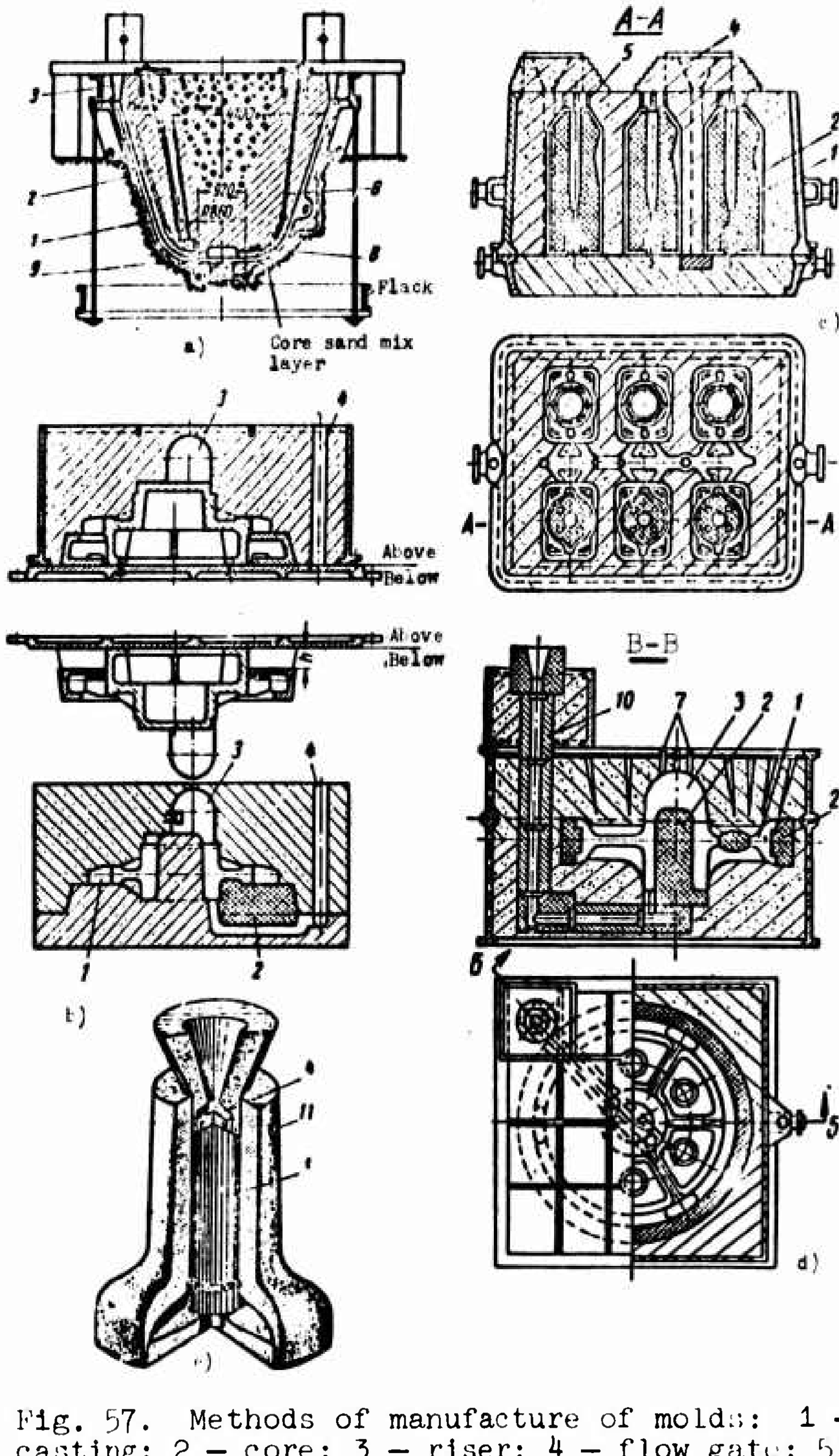


Fig. 57. Methods of manufacture of molds: 1 – casting; 2 – core; 3 – riser; 4 – flow gate; 5 – air hole; 6 – frame; 7 – flues; 8 – refrigerators; 9 – chaplets; 10 – ceramic tubes; 11 – chill mold.

Table 16. Methods of Manufacture of Steel and Iron Castings

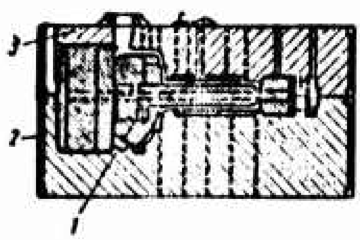
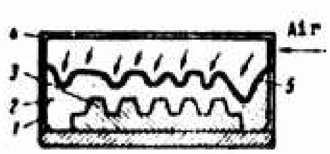
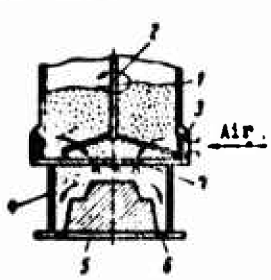
Method of casting	Process of manufacture of casting	Additional information
In sandy-clay forms 	By the drawing of the part a pattern and core block are made. The pattern externally corresponds to the external configuration of the part and the core box, to the internal cavity of the part. Dimensions of the pattern are increased as compared to the drawing of the part by the amount of shrinkage and allowance for machining. In the pattern the making of marks is anticipated. With the help of the pattern made of the core sand mix a mold is prepared, and with the help of the core box, and core. The core 1 is put in the lower half mold 2, which is closed by the upper half mold 3, after which the mold is flooded with metal. After hardening of the metal the form is destroyed and the casting removed.	Manufacture of forms in sand, in paired flasks, on molding machine and with the help of drawing models by the method of sandless molding. The following types of molding are used; wet, dry by the method of chemical hardening by liquid glass.
In forms, prepared on diaphragm machines 	Flask 1 is filled by the core sand mixture 2, transferred together with the pattern plate 3 to the compression mechanism 4, which constitutes a closed air reservoir hermetically sealed from the lower side by a thin rubber (diaphragm) 5. In the reservoir compressed air is put under pressure 6-7 kg/cm², which transmits pressure through a flexible rubber diaphragm to all parts of the mold adjoining it.	Different constructions of machines are used. The productivity of the machines for the manufacture of a mold in flasks 2000 X 865 X 225 mm 100 forms per hour.
In forms, prepared in core blowers and sand blasters. 	In the reservoir 1 is put the core sand mixture, which is loosened by the mixer 2. Compressed air proceeds through the hole 3, displaces sand through hole 7 into flask 4 and emerges through hole 6. The Table 5 rises and is lowered with the help of a pneumatic cylinder.	Semiautomatic and automatic multiposition core blowers are used. In sand-blast machines the operating cylinder is at the same time a receiving bunker, which hermetically is covered from above by a section gate.
In forms compressed under large specific pressure	A holding mixture is poured into the flask, installed in a drawing model plate, and it is compressed with the help of hinged-levered mechanism or hydraulic press.	Semiautomatic machines are used.

Table 16 (continued)

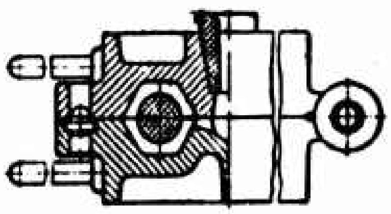
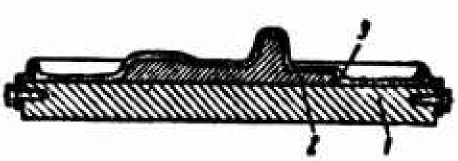
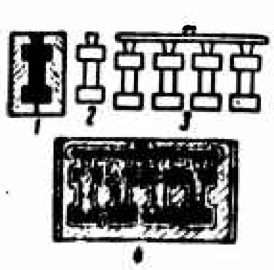
Method of casting	Process of manufacture of casting	Additional information
In chill mold 	Metal is poured into cast-iron or steel forms consisting more frequently of two parts. Along the parting line a casting configuration impression is made along with a flow gate system. For obtaining an internal impression and individual external parts of the casting sand cores are used which are put in the half mold; the form is secured and filled with metal, after solidification of the casting occurs.	Forms are used with horizontal, vertical and combined parting lines. A chill casting is produced on unit and vertical boring and turning machines.
In shell molds 	One-sided pattern plate 1 with metallic patterns is heated to 220-260°. On the heated pattern 2 is poured a molding mixture, consisting of fine quartz sand and thermoreactive synthetic tar (10%). For big molds instead of synthetic tar a chemical hardening mixture is used on liquid glass. The tar in the layer adjacent to the plate is melted and then solidifies forming on the pattern plate a uniform sand-resinous shell 3. After several minutes the molding mixture which has not been preheated out of the pattern is removed, the shell is separated from the plate and heated in an oven up to 230-300°. A hard, durable shell, constituting a half mold is coupled with the other shell of the half mold corresponding to it. In addition the cores are inserted as in the usual molding process. For larger molds, the shell is placed in an flask and it is covered with a cast-iron fraction.	For manufacture of shell molds semiautomatic installations are used.
By wax patterns 	Into the exactly prepared metal die pressure cast molds 1 melted alloy of paraffin and stearin is poured under pressure. After hardening, the pattern 2 is removed from the metal die pressure cast molds and attached in the form of a block to the general flow gate system. The block pattern 3 is dipped in a facing liquid compound consisting of hydrolyzed ethylsilicate with quartz meal and fine quartz sand is poured over it. This is repeated several times after which the block pattern is sweated several hours. The finished mold is put in a furnace or water heated to 100°; at this temperature the fusible compound melts and flows through the flow gate system. Then the mold is heated at 800-850°. The durable crust of the mold is formed into a flask 4 and filled with metal.	Molds can without shell in flasks and without flasks; shell molds with durable wet ir dry filler in flasks. The patterns melt from the shell in liquid or gaseous medium.

Table 1. (continued)

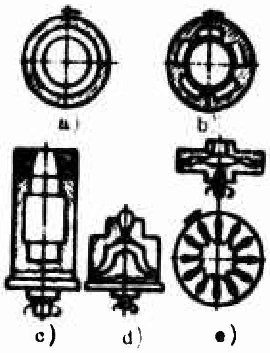
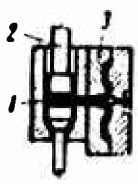
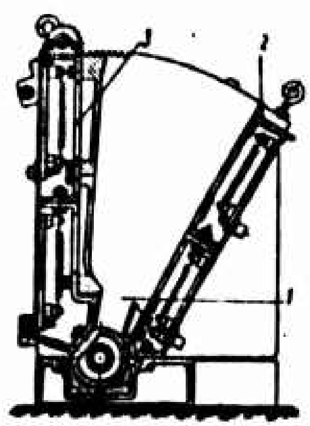
Method of casting	Process of manufacture of casting	Additional information
Centrifugal casting 	The metal poured in is thrown by centrifugal force to the peripheral part of the mold and hardens in this position. To form the internal surface of the casting, cores are not required. After hardening of the metal the rotation of the mold is stopped and the finished casting is extracted from it. By diagram a) any hollow casting may be made; by diagram b) small ingots and other castings, one of the surfaces of which has the form of a concave cylindrical section; by diagram c) dummies and hollers; by diagram d) gears, screw propellers, chain wheels for chain transmissions; by diagram e) faced, chiefly small castings.	The molds are rotated around a vertical axis; around a horizontal axis; around a skew axis; around an axis of variable angle of inclination in the process of manufacturing a casting; simultaneously around two axes located at right angles to each other.
Under pressure 	Liquid steel is poured into a compression chamber 1 and using the piston 2 under a pressure of more than 2000 kg/cm² it is put into a built-up mold 3. After solidification of the casting the mold is unclasp and the casting removed. Metallic cores are used.	Machines are used with horizontal and vertical compression chambers. Castings are obtained under laboratory conditions.
Squeezing 	Metal is poured into the hearth 1 by the foundry extrusion apparatus. On approaching the bolsters 2 and 3 the metal is squeezed from the hearth and fills the cavity of the mold between the dies. To get the internal cavity of the casting a core is installed.	Obtaining of thin-walled castings without cores and with cores.
Vacuum casting	The mold and ladle are placed in the chamber, from which the air is withdrawn, and filling is done in a vacuum.	Only the mold or the mold and ladle are placed in the vacuum chamber.
Vibration casting	During filling of the molds vibration of the metal is brought about.	Mechanical vibrations and ultrasonic vibrations are used.

Table 17. Area of Application of Different Methods of Casting

Method of casting	Region of application	Brief characteristic
Sandy-clay molds.	For manufacture of castings, which during molding require the use of a large number of cores for individual and small-lot production and casting of big parts. In mass production with a high degree of mechanization.	Large labor-consuminess and high primecost. Class of accuracy 8-9 by All-Union Government Standard 2789-61 and purity ∇ 1-∇ 3. Complex thin-walled castings are easily obtained; low accuracy of castings.
In chill molds.	Profitably in serial and mass production; with the same degree of mechanization as on casting in sand. For manufacture of thick-walled parts simple and average in complexity weighing from a kilogram to several tons. When it is required that we obtain durable metal in a casting subjected to hydraulic tests.	The castings are more accurate with smaller allowance on machining and heightened mechanical properties. It is difficult to obtain thin-walled castings of complicated configuration. The class of accuracy is 5-7, purity is ∇4-∇6.
In shell forms.	Profitably in serial production and mass production for castings with metal content up to 25-30 kg; with subsequent use of them without machining or with insignificant machining. Casting size up to 700 X 500 mm.	Obtaining of exact castings; class of accuracy 5-7, purity ∇3-∇5. The technological process is easily mechanized. High value of synthetic resins.
Dimensional shells.	Used for large castings. The biggest dimension is 2.9-11 m with a thickness of 60 mm. The shells are dismembered into several parts.	Small allowance on machining. Instead of synthetic resins chemical hardening mixtures are used.
By wax patterns.	It is economically expedient to pour parts by weight up to 350 g, earlier prepared by rolling or forging and subjected to machining, parts which require complicated machining, and also details, requiring complicated machining or prepared from alloys, which are poorly processed mechanically. The production of castings is convenient for output of 100 m/year of simple castings 500 piece, complicated - 50 piece.	Obtaining of castings of great accuracy. Class of accuracy 2-5, purity ∇4-∇7. Large labor-consuminess and high primecost. It is possible to pour parts with weight up to 10 kg, in certain cases of mass castings up to 50 kilogram. Dimensions up to 500 mm.
Under pressure.	Profitable in mass production. For manufacture of thin-walled castings of complicated configuration, but not having undercutting of the internal part of casting.	High productivity with great accuracy and cleanness of surface of the casting. Class of accuracy 3-5, cleanness ∇5-∇8. Low resistance of the metal die pressure cast molds and high resistance.
Squeezing.	Large dimension details with thickness of walls of 1 mm and area of several square meters.	The process of forming of the casting may be governed during approach of the bolsters. The casting obtained is dense.
Centrifugal casting.	Hollow solids of revolution (pipes, shells, rings) and shaped castings with heightened density or thin-walled.	It is possible to obtain the internal cavity of the casting without cores. However the exact dimensions of the opening are difficult to achieve.

Table 17 (continued)

Method of casting	Region of application	Brief characteristic
Pressing.	Thin-walled big casting with deep internal cavities.	The yield of suitable castings is 90-97%.
In semi-permanent molds.	Molds made of cement, asbestos graphite molds, glass molds, cermet, graphite, and stone molds are used for obtaining of big and average castings in serial production.	Several tens of castings can be obtained without destruction of the form; the castings are more exact than when using sand molds.

Table 18. Basic Conditions of Selection of Position of a Part During Filling

Conditions which should determine the position of the parts	Purpose	Region of application
Directed hardening of casting towards places of location of the most massive of its parts.	Prevention of rejects as a result of shrinkage cavities.	Small, average and big castings.
Location of basic processed surfaces chiefly from below on filling, but in the absence of such possibility – vertical or slanted.	Prevention of rejects as a result of sand holes and other faults.	The same
Location of well-developed flat surfaces of castings as far as possible from below on filling, either vertical or slanted.	The same	The same
Location of the thinnest walls in lower on filling parts of the mold and as far as possible in vertical or slanted position.	Prevention of rejects on underfilling.	Small and average castings.
Location from below on filling of protruding parts of the mold, if this will allow avoiding the use of cores.	Lowering of labor-consumingness of molding and core operations.	The same

Table 19. Basic Conditions of Selection of the Parting Plane of a Mold

Conditions, which must be provided for by the parting plane	Purpose	Region of application
Molding with application of the least number of cores.	Reduction of labor-consumingness of molding and core operations; increase in accuracy of dimensions of the casting.	Small, average and big castings.
Molding in flasks available in workshop.	Reduction of period of preparation of production and expenditures on manufacture of equipment.	Small, average and big castings prepared in small batches.
Molding in flasks of least height.	Reduction of expenditure of molding materials, possibility of organization of machine molding, lowering of labor-consumingness.	Chiefly small and average castings.
Location of basic surfaces of the part in one (chiefly the lower) half mold, and in the second, less critical parts.	Prevention of rejects for dimensions.	Small, average and big castings prepared in small batches.
Smooth parting plane of the mold instead of figured one.	Reduction of cost of manufacture of pattern set.	Unit and small-lot production.

For removal of the possibility of formation of shrinkage cavities in nodes and massive parts of casting during preparation of the mold installation of risers 5, 6 (Fig. 58), is anticipated which serve also as collections of surfacing nonmetallic inclusions or possible other separations.

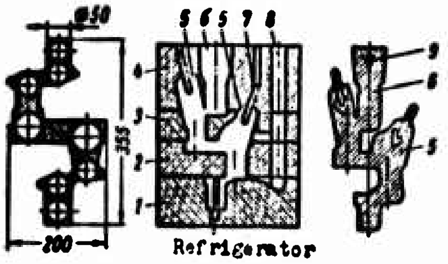


Fig. 58. Place of installation of riser on crankshaft: 1-4 — parts of the mold; 5 — closed risers; 6 — open riser; 7 — chuck for gas pressure; 8 — flow gate; 9 — shrinkage cavity.

The weight of the riser for steel parts constitutes 30-50% of the weight of the casting.

It is recommended that for selection of the place of installation and designation of the quantity, dimensions and form of the risers for a steel casting the following circumstances must be considered.

1. A shrinkage cavity will be formed in places of the casting, cooled by the latter; among them are all the most massive parts, local thickenings, junctures of separate elements of the piece and also the places of hampered heat radiation.

2. The shrinkage cavity strives to occupy the highest position in the casting.

3. Open risers are installed on the upper parts of the casting; closed ones, on the massive parts of the casting located inside the mold.

4. Putting risers in the massive parts of the casting slows the rate of cooling of the latter making possible an increase in residual tensions in it.

5. Placing of risers at places of concentration of stretching stresses developed in the casting at high temperature, promotes formation of hot cracks at these places during hardening of the casting.

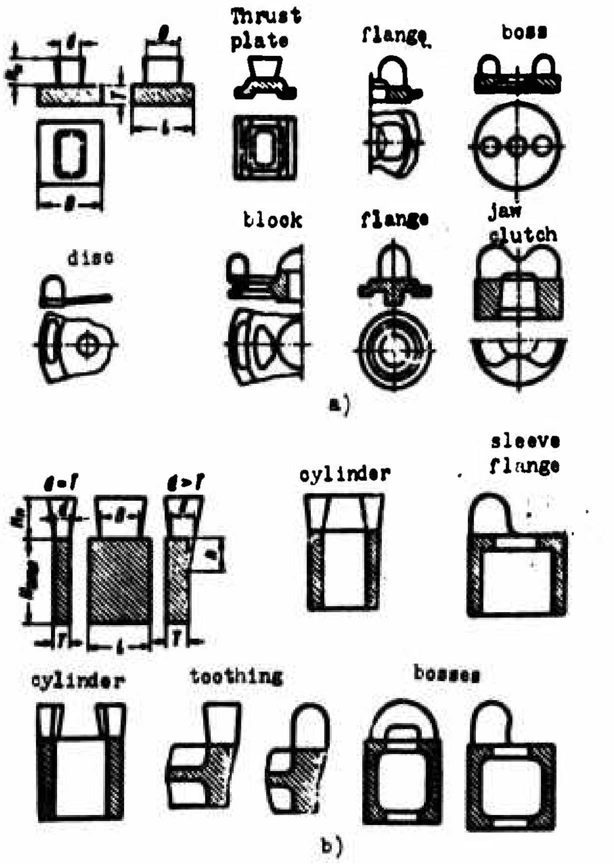


Fig. 59. Model diagram of location of risers: a) during filling horizontally; b) during filling vertically.

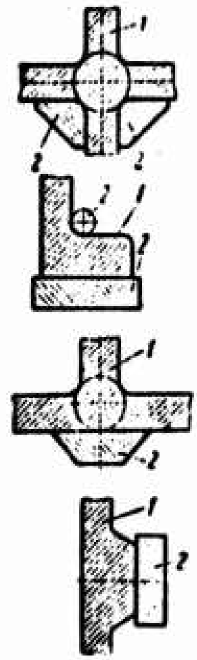


Fig. 60. Place of installation of refrigerators: 1 – casting; 2 – refrigerator.

6. Placing of risers on unprocessed part of casting leads to increase of expenditures on its machining.

Model diagrams of location of risers on different nodes of the castings are given in Fig. 59.

For cooling of local nodes and mainly thickened places of the casting, if the latter are not provided for by feeding from a riser, during manufacture of the mold refrigerators are installed – metallic inserts (Fig. 60).

Peculiarities in the Manufacture of Cores

In the construction of the internal part of a casting one should

consider the technology of preparation of the cores, fastening of them in the mold and removal from the casting.

In the determination of the boundary of the core it is possible to follow Table 20. Classification of cores by weight is given in Table 21, and by complexity of configuration, in Table 22.

Table 20. Basic Conditions for Selection of Core Boundaries

Conditions for selection of core boundaries	Purpose	Region of application
Separation of cores into separate parts (without lowering of its durability).	Simplification of manufacture.	When impossible to prepare cores without separation.
The core must have plane on the side of which it is convenient to carry out filling and installation of a frame.	The same	In all cases.
Provision for a simple surface, on which the core will be dried.	Prevention of breaking of cores during drying and transportation.	The same
Minimum quantity of removable parts.	Prevention of variation in dimensions and breaking of cores.	The same
Creation of sufficient stability in the mold.	Prevention of displacement of cores.	The same
Preventing of possibility of displacement of core during assembly and filling.	Prevention of rejects for dimensions.	The same
Guarantee of sufficient durability of the core.	Prevention of breaking of cores during manufacture, transport and installation of them in the mold.	The same
Preventing of possibility of surfacing of the core.	The same	The same

Table 20 (continued)

Conditions for selection of core boundaries	Purpose	Region of application
Limitation of the core in height.	Prevention of deformation of the wet core under effect of gravity.	Average and big castings
Guarantee of reliable expulsion of gases formed during filling of the mold.	Prevention of rejects of castings as a result of gas pockets.	In all cases.
Guarantee of possibility of manufacture of cores on core machines.	Lowering of labor-consumingness of manufacture and increase in quality of cores.	Small-serial, big-serial and mass production.

Table 21. Classification of Cores by Weight

Size	Weight in kilogram	Method of manufacture
Small	To 6	Manually or on core machines with edging and removal of boxes manually.
Average	To 100	Manually by core boxes or on core machines with edging and drawing after filling.
Big	Over 100	Manually by core box, on core machines or a sand slinger. Manufacture in operating position (without subsequent edging).

Table 22. Classification of Cores by Complexity of Configuration [1]

Class	Characteristic
I	Cores of complicated configuration with thin sections from all sides, washed by metal; in the casting are formed unprocessed internal surfaces, on the cleanness of which are imposed heightened requirements.
II	Cores of complex configurations, having, along with the basic compact part, very thin flanges; like cores of Class I in the castings completely or partially unprocessed internal surfaces are formed on the cleanness of which are imposed heightened requirements.

Table 22 (continued)

Class	Characteristic
III	Cores of simple configurations, forming in the castings open holes, on the cleanness of surface of which are imposed heightened requirements.
IV	Cores of average and simple configurations, forming in the castings unprocessed surfaces, on the cleanness of which no special requirments are imposed.
V	Massive cores, forming large internal cavities in big thin-walled castings.

Depending upon the binding materials and initial components of the core mixtures, cores of each class may be subdivided into sand-clay, sandy-butyric and cores made of special mixtures (in liquid glass, thermoreactive resin, cement and others). In addition, cores can be subdivided into volume and hollow (thin-walled) obtained by different methods.

The durability and rigidity of a core is ensured with the help of a metallic frame (Fig. 61) for removal of which in the casting it is necessary to anticipate a hole.

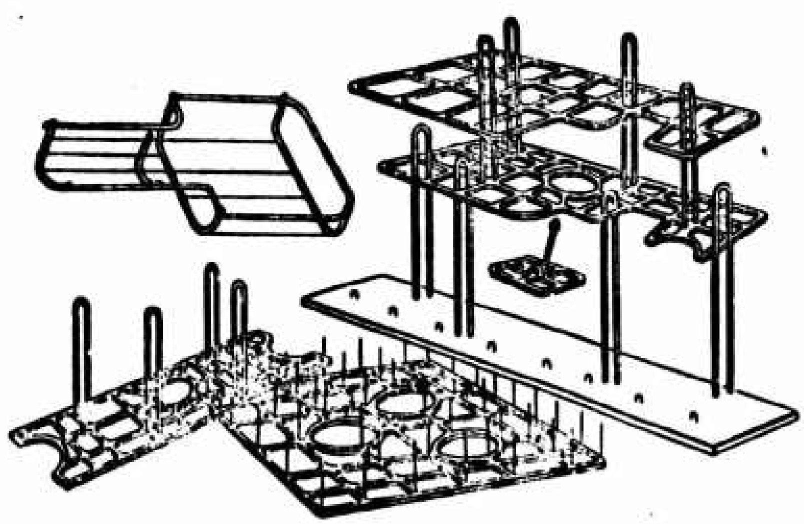
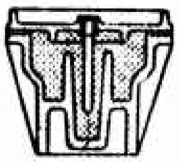
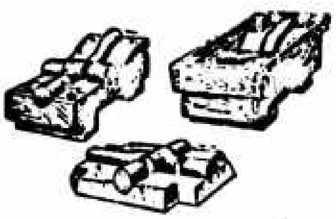
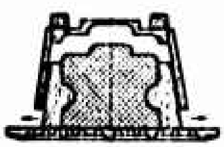
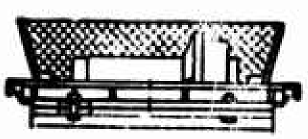
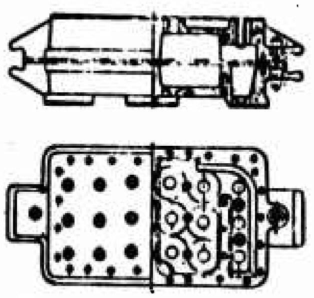


Fig. 61. Construction of frames.

Depending upon the size, configuration, series of production of the cores different methods of manufacture (Table 23) are used.

Table 23. Methods of Manufacture of Rods

Method of manufacture	Region of application	Sketch
By dropped core box.	If the core has recesses and protruding parts. The most productive method of production.	
By core box with a planar parting line.	For cores having a flat surface.	
By core box with a curvilinear parting line.	For cores of complicated configuration.	
By halves with subsequent joining.	The same	
By core boxes with removable parts.	If the core has recesses. Insufficiently productive method of production.	
On the core machines.	In big-serial production of cores.	
On core blowers and sand slingers.	In mass production of small and average by magnitude cores.	
With the help of a pattern.	In individual production, if the core have a rotation mold.	

Cores prepared in parts are assembled and in assembled form are placed in the mold (Table 24).

Table 24. Assembly of Cores [1]

Method	Technology
Gluing. One of the cores serves as a base for the others.	Before gluing, the cores are preliminarily cleaned, colored and checked. In order to avoid shifting of one core relative to another, they are fastened to linings, which are removed after drying of the glue.
Assembly in positioners. This is used for manufacture of big cores in mass production.	Assembly is done directly before installation of the cores in the mold by means of installation of separate cores in corresponding recesses of the positioner.
Assembly in mold jackets. This is used for assembly of complicated cores for thin-walled casting.	The mold jacket is a metallic box the cavity of which is accurately machined and serves for assembly of separate cores without gluing.

NON-FERROUS CASTING

The process of obtaining of intricately shaped parts by casting includes four basic steps:

1) Manufacture and preparation of the mold;

2) Smelting of the metal;

3) Pouring of the molten metal into the mold and hardening of the metal in the mold;

4) Separation of the castings from the materials of the mold and flow gates.

Basic Methods of Casting

Contemporary methods of casting, applied in machine building,

most frequently are classified (Table 25) depending upon the type of mold or method of filling it with molten metal. The majority of types of molds can be built by different methods.

Table 25. Methods of Casting and General Recommendations for Their use for Various Types of Nonferrous Alloys

Methods of pouring of metal into the mold	Molds			
	Nonmetallic			Metallic
	Sand (loam, shell, pressed).	Obtained by wax patterns	Gypsum	
Free (gravitational) filling.	Al-, Mg-, Cu-, Zn - alloys	Al-, Cu-, Ni-, Ti -alloys	Al-, Zn - alloys	Al-, Mg-, Cu-, Zn - alloys
Casting with directed crystallization	Al-, Mg - alloys	-	-	Al-, Mg - alloys
Casting by squeezing.	-	-	-	Al - alloys
Vacuum suction	-	-	-	Al - alloys
Casting under low (gas) pressure.	Al-, Cu- alloys	-	-	Al - alloys
Casting under pressure, created by a plunger	-	-	-	Al-, Mg-, Cu -, Zn - alloys
Drop forging from the liquid state.	-	-	-	Cu - alloys
Casting under the effect of centrifugal forces.	Cu - alloys	Cu -, Ni -, Ti - alloys	-	Al-, Cu- alloys
Casting in vibrating molds.	-	-	-	Al-, Cu- alloys

Note: Rectangle means that for a given alloy the corresponding method of casting is basic.

In Tables 26-29 are given accuracy of dimensions, allowance on machining, roughness of surface and minimum allowed thicknesses of walls in casting.

Table 26. Accuracy of Dimensions of Castings, Obtained by Different Methods [1]

Method of casting	Classes of accuracy by All-Union Standard 1013, 1014, 1015, 1016						
	3	4	5	7	8	9	Above 9
Casting in sand molds:							
by wooden patterns	—	—	—	—	—	X	X
by metallic models	—	—	—	X	X	X	X
Casting in shell molds	—	—	X	X	X	—	—
Casting by wax patterns	—	X	X	X	X	—	—
Casting in metallic molds (static teeming)	—	—	X	X	X	—	—
Casting under pressure in metallic molds	X	X	X	—	—	—	—

Table 27. Allowances on Machining of Castings, Obtained by Different Methods [1]

Methods of casting	Allowance on the side in mm for the biggest dimension of casting in mm			
	To 40	40-100	100-250	250-400
Casting in sand molds:				
manual molding	3.5	3.5	4	5
machine molding	2.5	2.5	3	4.5
Casting in shell molds	1	1.5	2	2
Casting by wax patterns	0.3	0.5	0.7	1
Casting in metallic molds (static teeming)	1	1.5	2	2
Casting under pressure in metallic molds	0.3	0.5	0.7	1

Table 28. Roughness of Surface of Castings, Obtained by Different Methods [1]

Methods of casting	Classes of cleanness of surface by All-Union Government Standard 2789-59								
	Rougher than 1	1	2	3	4	5	6	7	8
Casting in sand molds . . .	X	X	X	X	—	—	—	—	—
Casting in shell molds . .	—	—	—	X	X	X	—	—	—
Casting by wax patterns . .	—	—	—	—	X	X	X	—	—
Casting in metallic forms (static teeming)	—	—	—	X	X	X	X	—	—
Casting under pressure in metallic forms	—	—	—	—	—	X	X	X	—

Table 29. Minimum Allowable Thickness of Walls of Castings in mm for Various Methods of Casting [2]

Methods of casting	Alloys		
	Aluminum	Magnesium	Copper
Casting in sand molds	3.2-4.8	4.8-6.4	2.3-3.2
Casting in shell molds	1.6-3.2	1.6-3.2	1.6-3.2
Casting by wax patterns	—	—	0.76
Casting under pressure in metallic forms	1-2	1.3-2.5	—

On assignment of methods of casting it is necessary to consider also the following situations:

1. The number of methods of casting used in a given enterprise, should be as small as possible. Concentration in one foundry shop of technological variations which differ in principle from each other leads to breaking of the shop into small sections with comparatively low level of mechanization, diffusion of the strength of the technologists and as a final result, strongly hampers realization of advantages, embodied in the selected methods of casting.

2. Already during manufacture of a development type of article it is necessary to use the methods of casting which will be used in serial or mass production; the periods of mastering of serial technology of producing the castings, otherwise are extended significantly.

3. Methods of casting should be designated jointly with the technologist-foundryman.

The characteristics of methods of casting, which are universal may be found in the section "Steel and Iron Casting."

Molds

Basically during casting from nonferrous alloys the same types of molds are used as during casting of steel and cast iron. During

production of castings from comparatively low-melting (aluminum, magnesium, zinc) alloys casting engages significant specific gravity in metallic forms (in a chill mold and under pressure). In Table 30 is given the brief characteristic of the molds applicable to casting from aluminum alloys, the most widely used for production of intricately shaped castings.

Table 30. Types of Molds for Casting from Aluminum Alloys

Types of molds	Advantages	Deficiencies
Sand (loam), obtained by wooden pattern.	Technological equipment is prepared in short periods directly by drawings of parts. Simplicity of repair of equipment.	Low mechanical qualities of metal, accuracy of dimensions and cleanness of surface of castings. Heavy freight traffic.
The same, by metallic pattern	Accuracy of dimensions and cleanness of surface of castings two-three classes higher than in preceding case	The same, more prolonged periods of manufacture of equipment.
Shell molds from compounds on thermoreactive resins. Patterns are metallic	As compared to casting in sand molds significantly higher accuracy of dimensions and cleanness of surface of castings; smaller freight traffic in foundry shop.	More prolonged periods of mastering. Dimensions of molds should not exceed 600 × 800 mm
Sand molds, obtained by high pressure molding (order of 18-25 kg/cm²)	As compared to casting in usual sand molds higher accuracy of dimensions and cleanness of surface of castings; problems of process automation are more simply resolved.	At attained degree of mastery, the method is used for parts of comparatively small dimension and simple configuration
Nondetachable molds, obtained by wax patterns. Molds before filling are cooled to 200°	For manufacture of small delicate castings in small series more profitable than casting under pressure	Comparatively low quality of surface of castings and the worst properties of metal

Table 30 (continued)

Types of molds	Advantages	Deficiencies
Metallic forms (chill molds) with metallic and sand cores	As compared to casting in sand molds, the metal of the castings possesses higher mechanical properties due to increased speed of hardening; accuracy of dimensions and cleanness of surface of castings greater; significantly more hygienic conditions of work and smaller freight traffic in foundry shop	For manufacture of technological equipment and mastery of technology 2-3 times longer periods are needed than for casting in sand molds, obtained by wooden patterns
Metallic and sand molds with use of shell cores. Core boxes are metallic	By comparison to sand cores, greater accuracy of dimension and cleanness of surface for internal cavities of the castings	More prolonged period of mastery. Placement of refrigerators, necessary for obtaining of tight metal in nodes of castings is hampered
Gypsum molds	Cleanness of surface of castings approaches ∇6. Thanks to heightened filling properties of the mold it is possible to obtain thin-walled casting of complicated configuration.	Hardening is delayed which leads to lowering of mechanical properties of metal in casting up to 15%

Below is presented a short description of the process of manufacture of gypsum molds not used in production of castings of steel and cast iron.

Casting in gypsum molds [3]. A mixture of gypsum, asbestos and sand in ratio 4:1:5 on introduction into it of water goes into the liquid state and is poured into a flask with a pattern. In 15-20 minutes. The mixture hardens, the pattern is removed, and the gypsum mold is subjected to heat treatment at 600° for 8-10 hours. Before pouring of the aluminum alloys the mold is cooled to 20-200°.

Smelting of Nonferrous Metals

Selection of the type of smelting furnace depending upon the nonferrous alloy used may be performed in accordance with the recommendations of Tables 31 and 32.

Table 31. General Characteristic and Region of Application of Furnaces for Smelting of Nonferrous Alloys [2], [13]

Types of furnaces	General characteristic of furnaces		Alloys					
	Advantages	Deficiencies	Aluminum	Magnesium	Copper	Zinc	Nickel	Titanium
Electrical								
Resistances crucible furnace	Easy servicing, low-waste	Low productivity. Frequent replacement of cricible	+	+	—	+	—	—
Resistances chamber	Large capacity. Prolonged operation without repair	Local overheating of metal. Increased oxidation loss	+	+	—	—	—	—
Arc	High temperature during melting	Increased waste	—	—	+	—	—	—
Induction without core	Obtaining of metal of high quality with minimum porosity. High productivity	Comparatively low stability of packed crucible	+	+	+	—	+	+
Induction with core	The same	Manufacture of lining and conducting of melt require great art	+	—	+	—	+	—
Fuel								
Crucible hearth	Easy transition from melt of one alloy to other	High gas saturation of metal. Heightened waste. Low productivity. Inconvenient pouring	+	—	+	+	—	—

Table 31 (continued)

Types of furnaces	General characteristic of furnaces		Alloys					
	Advantages	Deficiencies	Aluminum	Magnesium	Copper	Zinc	Nickel	Titanium
Crucible turning	The same, but waste less; pouring is more convenient	The same, except for pouring	+	–	+	+	–	–
Flame	The same	The same	–	–	+	–	–	–

Note: Recommended types of smelting furnaces are marked by small crosses.

Table 32. Characteristic of Furnaces for Smelting of Nonferrous Alloys

Types of furnaces	Brands of furnaces	Basic assignment	Characteristic of furnaces			Average productivity in kg/hr	Waste of metal in %
			Capacity in kg	Expenditure on 1 m of liquid metal			
				electric power in kw/hr	conditional fuel in kg		
Resistance crucible turning	CAT 0.15A	Melting of aluminum alloys	150	550-600	–	50	–
The same . .	CAT 0.25A	The same	250	550-600	–	75	–
The same . .	CAT 0.5A	The same	500	550-600	–	125	–
Resistance crucible stationary. . .	CAT 0.15B	The same	150	550-600	–	50	–
The same . .	CAT 0.25B	The same	250	550-600	–	75	–

Table 32 (continued)

Types of furnaces	Brands of furnaces	Basic assignment	Characteristic of furnaces: Capacity in kg	Expenditure on 1 m of liquid metal: electric power in kw/hr	Expenditure on 1 m of liquid metal: Conditional fuel in kg	Average productivity in kg/hr	Waste of metal in %
The same . .	CAT 0.5B	The same	500	550-600	–	125	–
The same . .	CAT 0.15C	Pre-heating aluminum alloys	150	110	–	–	–
The same . .	CAT 0.25C		250	110	–	–	–
Resistance chamber stationary. . .	CAK 0.15A	Melting of aluminum alloys	150	650	–	55	–
The same . .	CAK 0.25A		250	600	–	75	–
Resistance chamber turning	CAH 0.3A	The same	300	550	–	–	–
The same . .	CAH 0.5A	The same	500	550	–	–	–
The same . .	CAH 1.0A and 1.0B	The same	1000	550	–	–	–
The same . .	CAH 1.5A	The same	1500	550	–	–	–
The same . .	CAH 2A and 2B	The same	2000	550	–	–	–
Resistance chamber slanted.	CAM 0.5	Pre-heating aluminum alloys	500	45-50	–	550	1
The same . .	CAM 1.0	The same	1000	35-40	–	1500	1.5

Table 32 (continued)

Types of furnaces	Brands of furnaces	Basic assignment	Characteristic of furnaces			Average productivity in kg/hr	Waste of metal in %
			Capacity in kg	Expenditure on 1 m of liquid metal			
				electric power in kw/hr	conditional fuel in kg		
Induction witout core . .	Yakovlev construction	Melting of magnesium alloys	350	450-550	–	300	2-3
Arc chamber pumped .	DMK 0.1	Melting of copper alloys	100	320-450	–	120-170	
The same . .	DMK 0.25	The same	250	250-350	–	200-320	1.5-4
The same . .	DMK 0.5	The same	500	200-300	–	350-570	1.5-4.5
The same . .	DMK 1.0	The same	1000	190-290	–	600-900	1.5-5
	DMK 2.0	The same	2000	150-230	–	900-1500	2-5
Induction with core	ILO 0.3	The same	300	200-290	–	230-370	0.6-2.5
The same . .	ILO 0.6	The same	600	230-330	–	300-500	0.6-2.5
The same . .	ILO 0.75	The same	750	195-280	–	750-1250	0.6-2.5
The same . .	ILD 1.2	The same	1200	230-330	–	500-920	0.6-2.5
The same . .	ILD 2.0	The same	2000	210-300	–	770-1400	0.6-2.5
The same . .	ILT 1.5	The same	1500	195-275	–	2200-3700	0.6-2.5
The same . .	ILT 3.0	The same	3000	195-275	–	2200-3700	0.6-2.5

Table 32 (continued)

Types of furnaces	Brands of furnaces	Basic assignment	Characteristic of furnaces: Capacity in kg	Expenditure on 1 m of liquid metal: electric power in kw/hr	Expenditure on 1 m of liquid metal: conditional fuel in kg	Average productivity in kg/hr	Waste of metal in %
Crucible hearth .	–	Melting of copper alloys	100-150	–	300-400	70-100	1.2-2.5
Crucible hearth .	–		100-200	–	150-200	90-140	1-2.5
Crucible turning . .	–	The same	100-200	–	150-200	120-180	1-2.5
The same . .	–	The same	100-250	–	80-100	130-170	1.2-2.5
Drum turning	"dream"	The same	250	–	140-160	190-220	5-9
The same . .	The same	The same	500	–	130-150	280-350	5-10
The same . .	The same	The same	1000	–	120-140	400-500	6-10
The same . .	The same	The same	2000	–	100-120	700-900	6-10
Flame hearth .	"Econo-melt"	The same	350	–	120-150	200-250	6-9
The same . .	The same	The same	750	–	120-150	350-450	6-9
The same . .	"Geo-gradze"	The same	400-700	–	110-220	250-350	2.5-5

Methods of Filling of Molds

In Table 33 is given the general characteristic of methods of filling of molds during casting from nonferrous alloys.

Below is presented a short description of separate methods of pouring of metal in molds.

Table 33. General Characteristic of Methods of Pouring of Metal into a Mold

Method	Advantages	Deficiencies
Free (gravitational) pouring of metal in forms	Possibility of pouring of metal into molds, prepared by any known method. Application of the simplest equipment and attachments. The most studied method of filling	Limited possibilities of adjustment of speed of filling of mold with metal, which leads to underfilling of thin walls on the one hand, and to holding of nonmetallic inclusions by metal on the other
Casting with directed crystallization	This permits obtaining of a casting from aluminum and magnesium alloys with thickness of body up to 3 mm with extent up to 3000 mm which ensures lowering of expenditure of metal by 2-4 times and labor-consumingness of manufacture of castings by 25-30%, and also significantly reduces expenditure of labor on manufacture of parts	Specific insufficiently studied forms of foundry rejects. Complexity of adjustment of technological process. Limited nomenclature of poured parts
Casting by squeezing	Possibility of obtaining of thin-walled panels, including ribbed, with area of several square meters. Tight structure of metal in casting	Limited nomenclature of castings. Unique insufficiently studied forms of foundry rejects
Vacuum suction	Obtaining of tight castings with high mechanical properties. High productivity of process	Limited nomenclature of obtained castings. Unique insufficiently studied forms of foundry rejects
Casting under low pressure created by gas medium	At the expense of combination of laminar flow of metal during filling of form with heightened pressure it is possible to obtain thin-walled castings by extent up to 1200 mm with relatively tight structure	Possibility of saturation of metal by gases during creation of pressure in crucible. Process is complicated and is studied insufficiently.

Table 33 (continued)

Method	Advantages	Deficiencies
Casting under pressure, created by a plunger, without vacuum in the mold. The mold is made of metal [5] [14]	Possibility of obtaining thin-walled complicated parts with dimensions up to 1000 mm and more with precision of dimensions up to 5-3 classes and cleanness of surface to ∇7 by All-Union Government Standard (see Tables 26-29). The most highly productive method of casting	Due to high speed of filling of form, in the castings are formed small air inclusions and shrinkage cavities which predetermines lowered airtightness and durability of poured parts. Prolonged period of mastering of technology
Casting under pressure, created by a plunger. In the mold before filling there is created a vacuum	The same, significant lowering of volume of air inclusions and shrinkage cavities; simple castings are obtained tight	More prolonged period of mastery as compared to preceding. Alteration is necessary and filling out of casting machines under pressure. Presence of small air-shrinkage porosity
Drop forging from liquid state	High accuracy of external dimensions, cleanness of edges and cleanness of surface for castings. Metal of castings is distinguished by high density. Flow gate-feeding system is absent; yield of suitable casting is 90-95%. It is possible to use standard hydraulic presses	Region of application is limited to small parts of comparatively simple configuration
Centrifugal casting with horizontal axis of rotation	Possibility of obtaining ring pots and similar solids of revolution with small expenditures of labor and without expenditure of metal on flow gates. Metal of castings has tight structure	Region of application is limited to comparatively small parts in the form of hollow cylindrical solids of revolution
Centrifugal casting with vertical axis of rotation	Heightened pressure in metal ensures good execution of thin walls in castings and obtaining of tight metal in nodes	Limited dimensions of obtained intricately shaped castings. Mold can not sustain developed forces and is deformed or is destroyed

Table 33 (continued)

Method	Advantages	Deficiencies
Casting in vibrating molds	Filling with metal of narrow cavities of mold is improved, more total purification of metal of non-metallic inclusions is achieved. Metal of cast castings has more refined structure and durability characteristics are increased up to 10-15%	Molds have to possess sufficient durability and during vibration not be destroyed

Casting with directed crystallization (see Fig. 62). Before filling, the mold is installed on the pattern of a hydraulic hoist. Above the mold is put a pouring basin, the tubular flow gates of which enter the flow gates-walls of the mold. Entrances in the tubular flow gates are covered by corks. The pouring basin is filled with metal the cork is opened, and metal overflows through the tubular flow gates into the lower part of the mold. By the extent of filling the mold form is lowered with a rate determined by the linear crystallization rate of the casting by height. During the entire period of filling the hottest metal is in the upper part of the mold, thanks to which is ensured directed-consecutive crystallization of casting.

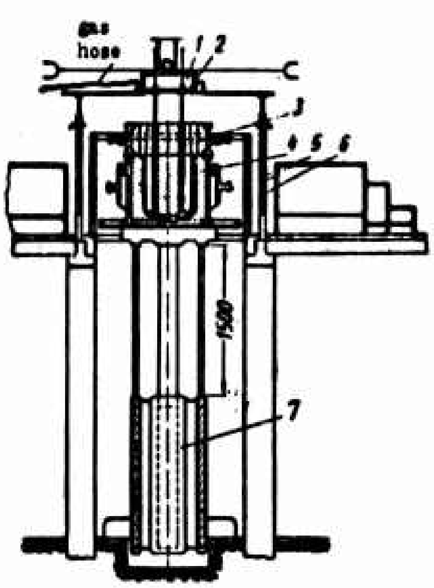


Fig. 62. Diagram of installation for manufacture of large dimension thin-walled castings by method of directed crystallization: 1 — pouring basin; 2 — tubular flow gates; 3 — flow gates-wells in mold; 4 — mold; 5 — sliding rods; 6 — supports; 7 — hydraulic hoist.

Casting by squeezing [6]. Molten metal is poured into the lower part of the open mold (Fig. 63).

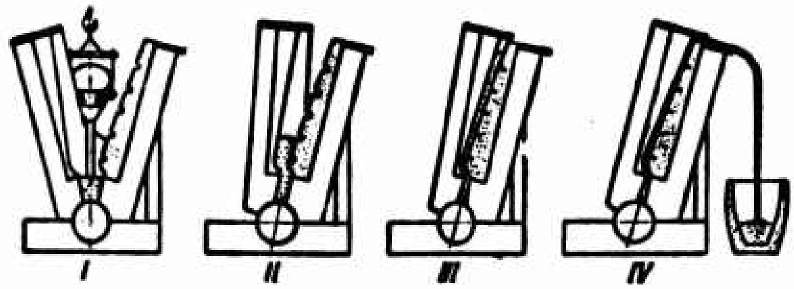


Fig. 63. Diagram of process of casting by squeezing: I — pouring of metal in mold: II, III — appraoch of half molds with formation at the walls of layers of hardening metal; IV — joining of layers into monolithic wall.

Then the halves of the mold are brought together and the metal is squeezed upwards, filling the mold. According to the closeness of the walls of the mold a layer of hardened metal is formed which is joined into a monolithic wall at the end of the bringing of the walls together. The surplus metal with the inclusions in it is forced out.

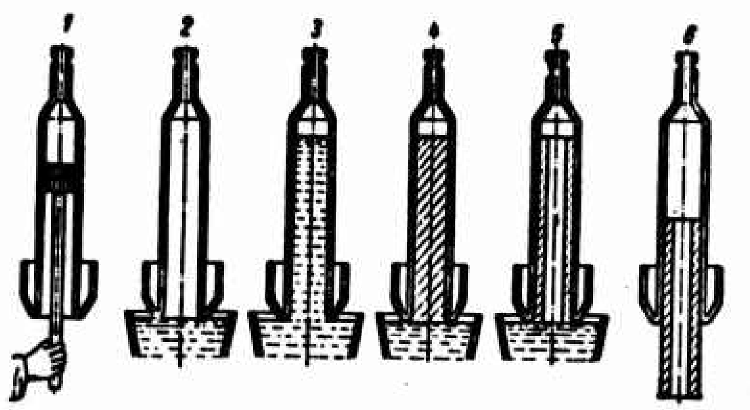


Fig. 64. Diagram of obtaining of hollow castings by method of vacuum suction: 1 — lubrication of mold; 2 — submersion of nose of mold in metal; 3 — suction of alloy into mold; 4 — holding for hardening of alloy; 5 — pouring of liquid part of alloy in bath; 6 — removal of casting.

Vacuum suction (Fig. 64). A metallic mold-crystallizer cooled by water is dipped to small depth in a bath with molten metal. In

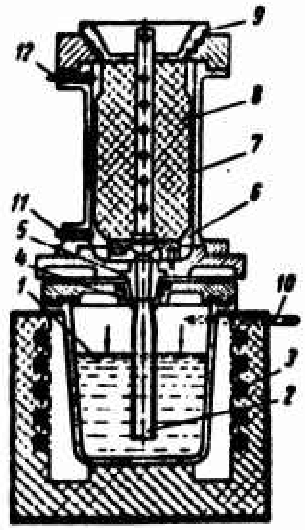


Fig. 65. Diagram of installation for casting under low pressure: 1 — crucible; 2 — metal conduit; 3 — electric heaters; 4 — head of metal conduit; 5 — flow gate sleeve; 6 — collector; 7 — die; 8 — core; 9 — filter; 10 — pipe for supply of gas; 11, 12 — contacts.

the cavity of the crystallizer is created a rarefaction, and metal is drawn into the mold to a definite height. After the given time necessary for formation of a hard layer of the needed thickness, the rarefaction is removed, and the part of the metal which has not hardened flows back into the bath.

Casting under low pressure [7]. A metallic mold with metallic, sand or shell cores is installed above a hermetic steel crucible (Fig. 65), into which after fastening of the mold flows compressed air or inert gas, and the metal is moved by a pipeline and flow gate system into the form. The rate of filling of the mold is regulated by the pressure of the gas.

Casting under pressure [14]. Molten metal (most frequently zinc or aluminum alloy) is poured into a cylindrical pressure chamber and using a plunger under high pressure is pressed into a metallic mold (Fig. 66). Thanks to high rates of flow of metal good execution of thin walls is ensured and also good edges on the casting. At the same time the high rate of flow evokes turbulent motion of the metal, as a result of which part of air of form does not succeed in emerging through the gaps and is mixed with the metal, forming cavities in the casting. Therefore casting under pressure is used mainly for manufacture of parts, not subjected to dynamic loads and heat treatment, during which the air in the casting is expanded, forming on the

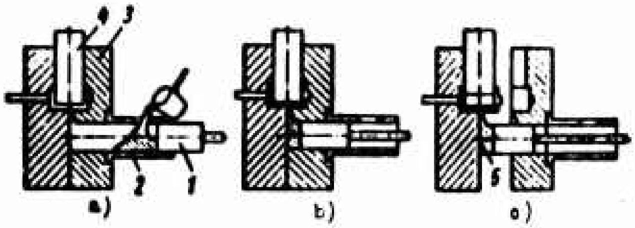


Fig. 66.

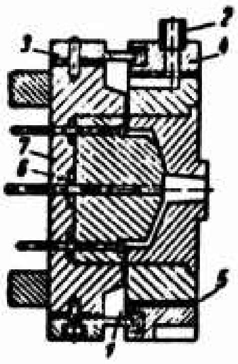


Fig. 67.

Fig. 66. Diagram of process of casting under pressure on a machine with horizontal pressure chamber; a) filling of chamber with alloy; b) pressing; c) opening of mold; 1 – plunger; 2 – pressure chamber; 3 – mold; 4 – metallic core; 5 – casting with flow gates.

Fig. 67. Diagram of a vacuum mold for casting under pressure; 1 – ventilation channels; 2 – stub pipe; 3, 4 – cover plates; 5, 6 – linings; 7 – casting.

surface of the castings characteristic swelling.

Casting under pressure with application of vacuum [14]. This differs from the preceding method by the fact that before pouring of the metal a significant part of the air in the mold is pumped out of it (Fig. 67).

Drop forging of metal from liquid state (liquid stamping) [4]. A definite portion of metal is poured into an open mold (Fig. 68). Then the metal is pressed upwards by a ram forming the casting. The pressure of the ram is not removed until the end of hardening of the casting.

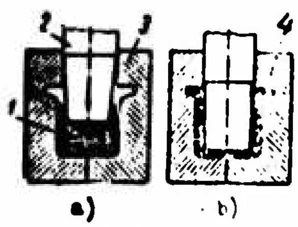


Fig. 68. Diagram of stamping of metal from liquid state; a) at beginning of pressing; b) after pressing; 1 – molten metal; 2 – ram; 3 – die; 4 – ready casting.

Centrifugal casting with horizontal axis of rotation (Fig. 69). Into a revolving mold through a motionless groove is poured the metal. In the mold the metal under the effect of centrifugal force is pressed to the walls, forming a solid of revolution. The

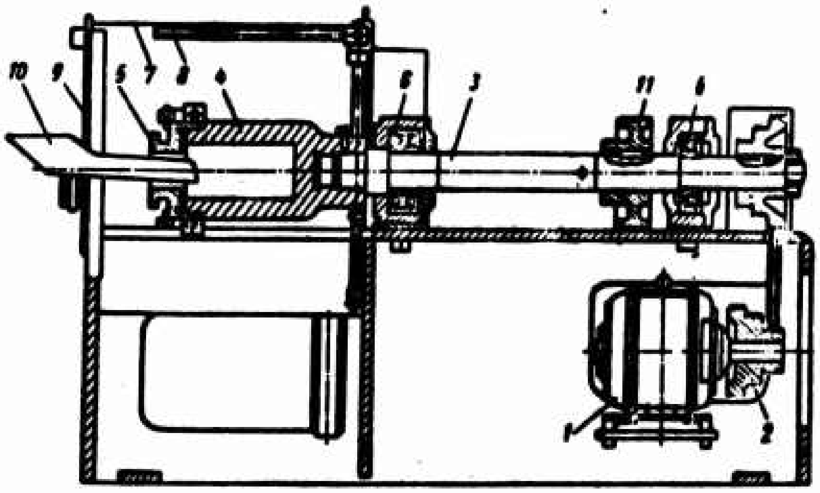


Fig. 69. Centrifugal machine with horizontal axis of rotation: 1 — electric motor; 2 — pulleys; 3 — shaft; 4 — metallic mold; 5 — cover; 6 — ballbearings; 7 — housing; 8 — tube; 9 — door; 10 — groove; 11 — braking pulley.

rotation is ceased after full cooling of the casting. Application of sand cores allows obtaining of castings with a complicated external profile.

Centrifugal casting with vertical axis of rotation (Fig. 70). A definite portion of molten metal is poured via a flow gate funnel into a revolving mold. Under the effect of centrifugal force the metal fills the cavity of the mold located at the periphery, forming castings and local flow gates.

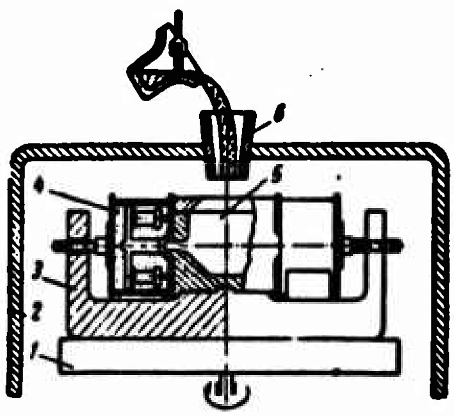


Fig. 70. Diagram of centrifugal casting with vertical axis of rotation; 1 — face plate; 2 — shell; 3 — crosspiece; 4 — mold; 5 — hearth; 6 — funnel.

Casting in vibrating molds [8]. Molten metal in the process of filling of the mold and hardening is subjected to the influence of rapidly alternated dynamic pulses, at which the metal alternately is in a

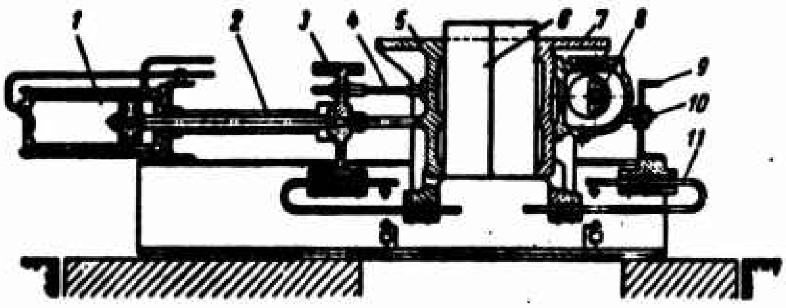


Fig. 71. Diagram of vibration foundry machine: 1 — pneumatic cylinder; 2 — rod; 3 — crossarm; 4 — flexible connecting rod; 5 — left plate; 6 — mold; 7 — right plate; 8 — inertial vibrator; 9 — channel; 10 — bolt; 11 — spring.

state of compression as a result of increase of its effective weight. In periods of weightlessness from the metal gases separate and intensely inclusions coagulate; in periods of compression inclusions are ejected to the surface of the metal as a result of increasing the difference of specific gravities.

In Fig. 71 is presented a machine for casting in vibrating molds. On removal of the chill mold and approach of plates 5 and 7 in their upper horizontal plane it is possible to install sand or other molds. For casting from aluminum alloys, the frequency of oscillations is changed from 3 to 500 cycles/sec and amplitude, from 0.5 to 10 mm.

Peculiarities of Technology of Casting of Certain Alloys

Aluminum alloys. For manufacture of castings from aluminum alloys many methods of casting (see Table 25) are successfully used. Low melting temperature (order of 700°) allows wide use of casting in metallic molds. For manufacture of castings of critical assignment the most favorable combination of high accuracy of dimensions,

cleanness of surface of castings and quality of metal in casting with low primecost of casting and high culture of production is attained on casting in chill molds with the use of shell and sand cores. Full replacement of sand cores by shell is limited by the difficulty of installation in this case of refrigerators, necessary to guarantee directed crystallization of the metal. Many body and other parts, not tested for airtightness and not carriers of large loads are successfully prepared by casting under pressure.

The quality of casting under pressure is essentially improved by evacuating the form. Still to a larger degree quality of details, obtained by casting under pressure is increased, on use of apportioning filling devices (Fig. 72). In this device the technologically required rate of supply of metal to the chamber of the casting machine under pressure is ensured as a result of flow of metal through a calibrated opening under definite hydrostatic pressure which is kept within given limits during lowering of the displacer according to the degree of expenditure of metal in the crucible.

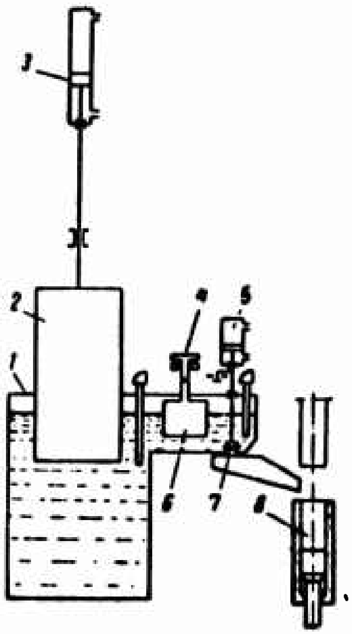


Fig. 72. Diagram of automatic apportioning installation DU-5 for pouring of aluminum alloys; 1 — crucible of furnace; 2 — displacer; 3 — hydraulic drive of the displacer; 4 — terminal switch; 5 — pneumatic cylinder; 6 — float; 7 — stopper; 8 — pressure chamber of casting machine under pressure.

<u>Magnesium alloys</u> [9]. Smelting of alloys is done under a solid covering layer of fluxes, consisting basically of a mixture of chloride and fluoride compounds. Fluxes

have two assignments:

1) Protect alloy from oxidation and ignition;

2) Refine alloy by means of removal of nonmetallic impurities which are in the alloy in suspension. For more total and rapid refining the alloy is energetically mixed and then left to settle. In the process of standing, nonmetallic inclusions settle to the bottom of the crucible which in the appropriate way is considered during pouring.

For the purpose of crushing of grain and respectively improvement of the mechanical properties, magnesium alloys are refined by means of overheating to a temperature of 850-900° or introduction into the melt of carbon containing substances. Magnesium reacts with moisture of the mold, nitrogen of the atmosphere and silica. Reactions proceed with significant liberation of heat as a result of which casting can catch fire; for preventing of ignition, into the forming mixtures are introduced protective additives, for example, ammonium fluoride, sulfur, boric acid. Decomposing or reacting with magnesium or products of oxidation of magnesium, the additives form protective films or insulating gas layers.

Copper alloys [10]. For prevention of saturation of liquid copper alloy with hydrogen, leading to significant drop in the mechanical characteristics of the metal and appearance in the casting of cavities, special measures are taken: Thorough selection and heat treatment of the charge before melting, carrying out melting in oxidizing atmosphere, deoxidation of metal by phosphorous copper. During manufacture of critical parts to the casting is allowed liquid metal only for sufficient plasticity of the alloy and absence in it of gas cavities which is determined by technological samples.

Calm filling of the mold is ensured by application of braking flow gate systems, filtering grids and correct selection of temperature of filling. Modification of certain copper alloys by small additives containing V, B, Ti and certain other substances, leads to refinement of structure, improvement (to 20%) of mechanical properties of the alloys.

Zinc alloys. Comparatively low melting temperature and high fluidity of alloys allows obtaining from them of very small thin-walled parts. Parts made of zinc alloys are cast chiefly under pressure. They are melted most frequently in electrical resistance furnaces, in graphite crucibles under a layer of crushed carbon; for 20-30 min before pouring the alloys are purified with ammonium chloride.

Nickel alloys [11]. For nickel alloys high melting temperatures, strong oxidizability and energetic absorption gases during melting and pouring, large inclination to formation of carbides are characteristic. Therefore, they are melted for intricately shaped castings in induction vacuum furnaces. The crucible is made by sintering from granular electrocorundum or fused magnesite. Sintering of the lining is carried out with the help of a graphite core lowered into the crucible. After loading of the charge directly a heated mold is installed in the crucible made wax patterns, and the furnace is closed by a shell and hermetically sealed. Metal is melted and brought to the temperature of filling (1600-1650°). From the beginning of melting in the chamber of the furnace there is created a vacuum, corresponding to a residual pressure of the order of several tens of microns of mercury. Pouring of metal into the molds is produced by means of rotation of the crucible under vacuum after

releasing the surface area of the metal. In most cases melting-filling vacuum furnaces work on a periodic cycle, for which after every filling the vacuum is removed and the furnace opens. In vacuum furnace IVP-10/20 liter the mold is installed directly above the crucible (Fig. 73). Before filling the mold is lowered into the furnace and is rotated with the furnace by 180°.

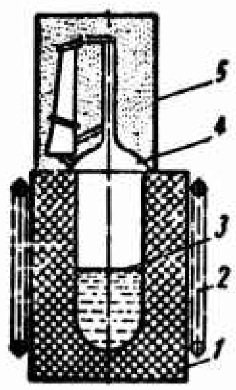


Fig. 73. Diagram of turning crucible of furnace IVP 10/20 liter; 1 — crucible; 2 — inductor; 3 — level of molten metal; 4 — flow gate funnel; 5 — mold.

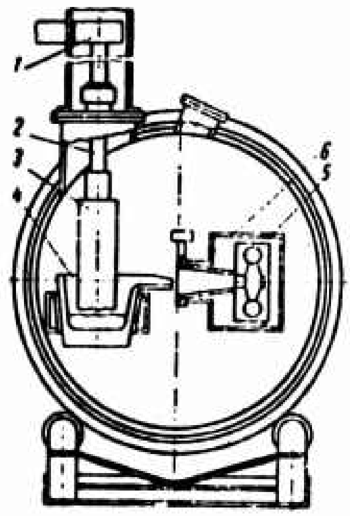


Fig. 74. Diagram of arc furnace for shaped casting of titanium alloys; 1 — currentfeed; 2 — electrodeholder; 3 — electrode made of titanium; 4 — graphite crucible; 5 — mold; 6 — housing for mold.

Titanium alloys. Titanium has a high melting temperature (order of 1690°). But the main difficulties during casting from titanium alloys are connected with the high chemical activity of titanium in the molten state. Easily being saturated with oxygen, nitrogen and hydrogen, it becomes fragile, hard and badly fit for machining. Titanium reduces even very refractory oxides BeO, TiO_2, MgO, stabilized ZrO_2. Products of dissociation especially during preparation of large parts strongly contaminate the surface of the castings to a

depth of 1 mm and more. For casting of titanium alloys the most stable are molds made of graphite, which practically very weakly react with titanium. It is well known that one can obtain comparatively simple castings from titanium alloys in molds made of steel and cast iron. During melting in induction furnaces with a graphite crucible, titanium absorbs a significant quantity of carbon (to 0.3-1%), in consequence of which plasticity, viscosity and weldability of the alloys is worsened. Fireproof crucibles from material which does not contaminate the metal are unknown. Successful melting of titanium alloys is possible only in a lining i.e., in a crucible, on the walls of which after the first melts there remains a small layer of hardened titanium which protects the molten metal from contact with the crucible. In Fig. 74 is shown a domestic furnace for melting and pouring of titanium alloys [12], allowing the obtaining of parts weighing 10-15 kg. The graphite crucible of the furnace for preservation of the lining is cooled by a water jacket. As an expendable electrode is used an ingot of the first melting or a forged blank. A mold made of graphite is placed opposite the nose of the crucible and is filled during rotation by 90° of the entire furnace set on rollers. Melting and pouring are conducted at residual pressure in the furnace of the order of $1 \cdot 10^{-1}$ mm Hg. For pouring of titanium alloys siphon or slot flow gate systems are recommended.

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CHAPTER II

TECHNOLOGY OF FORGING AND STAMPING

FORGING AND HOT STAMPING

Influence of Hot Processing by Pressure on the Properties of Steel [10], [11], [15], [22], [28], [30]

Influence of forging on macrostructure. As a result of forging (rolling) cost metal acquires a fibrous macrostructure (Fig. 1). This forces during appraisal of mechanical qualities of forgings consideration of direction of cutting of the sample – along or across the fibers.

a)

b)

c)

Fig. 1. Macrostructure of steel (I. G. Sokolov): a) poured; b) with forging ratio 1.5; c) with forging ratio 4.5.

The fibrous macrostructure of forged (rolled) steel is a fully stable formation. It cannot be destroyed by heat treatment or subsequent treatment by pressure; in the latter case, the rectilinear direction of the fiber can only become curvilinear.

Influence of forging on mechanical qualities. On the limit of strength σ_B, yield point σ_T and limit of proportionality, $\sigma_{пц}$ hot processing by pressure practically has no residual influence.

This means that after identical heat treatment with reduction to identical microstructure in samples, forged with various degrees of forging* the indicated characteristics are practically identical.

On shock viscosity a_{Π}, transverse narrowing ψ, lengthening δ and limit of strength σ_{-1}, forging (a poured ingot) has noticeable residual influence. These characteristics in longitudinal (along fibers) samples with increase of degree of forging ratio approximately to 10 increase (especially intensely to degree of forging 2.5-3.5), and further remain stable, and in transverse samples (across the fibers) they progressively drop and only in special cases with small degrees of forging have a tendency toward insignificant improvement.

Considering this anisotropy of mechanical qualities, it is possible to recommend for constructional steels a degree of forging [ratio of cross sectional area of original ingot to area of drawn billet] not more than 2.5-3.5 in those cases, when impossible to ensure coincidence of direction of fibers with direction of the biggest normal stresses in parts during use (for instance, seamless-forged vessels and pipes, subject to internal pressure, flange of crankshafts with short journals etc.). When it is possible to ensure direction of fiber, differing little from direction of biggest normal strain, a forging ratio of 5-6 and more is permissible.

Influence of forging on micro-structure. Hot forging of constructional steel, conducted at regular thermomechanical conditions has no residual influence on microstructure. The latter is determined by heat treatment.

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*Degree of forging is the ratio of area of initial cross section of ingot to area of cross section of forged blank.

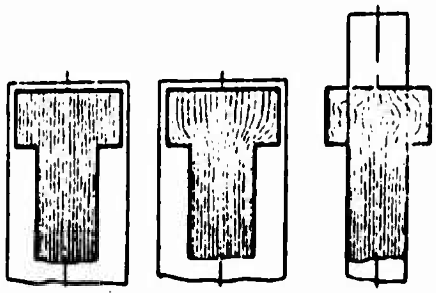
However it is necessary to try to obtain after forging a fine-grained structure. In this case forging will have maximum possible in untreated form mechanical qualities, and subsequent heat treatment will be facilitated.

Hot forging of steel having in poured state a microstructure with presence of cementite grid or big grains of carbides, renders very favorable influence on the quality of articles, destroying the grid and crushing the carbides.

Cold forging causes physical strengthening of metal (cold-hardening), removed by heat treating.

Conditions of manufacture of forgings, ensuring high quality of the part. Best mechanical qualities of forgings are ensured by the following conditions: 1) correctly selected for given detail degree of forging; 2) coincidence of direction of fibers with direction of the biggest normal stresses, appearing during use of the detail (when impossible to have this condition it is necessary to take measures to lower the heterogeneity of mechanical qualities along and across the fibers by means of preliminary setting, distribution on mounting or other method); 3) direction of fibers in accordance with contour of detail — fiber should not be cut across; 4) absence of displacement of the axial zone of ingot to the surface of the forging; 5) observance of correct thermomechanical conditions of forging (see p. 85).

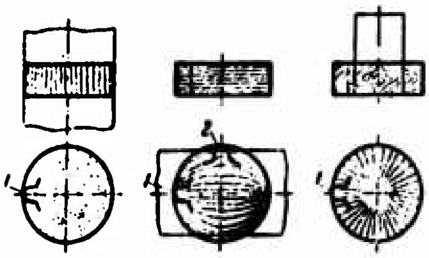
Examples: 1. A bolt, obtained by cutting a rod (Fig. 2a), has unsatisfactory macrostructure of head — normal stresses are directed across fibers. Furthermore, rod of bolt is formed from the central zone of the initial rolled rod, possessing lowered qualities. A bolt, prepared by means of drawing of rod (Fig. 2b), does not possess last deficiency and has more favorable direction of fiber.



a) b) c)
Fig. 2.

Manufacture of bolt (Fig. 2c) by upsetting of head from a rod of diameter, equal to the diameter of the bolt shaft allows obtaining of a head with the most favorable location of fibers.

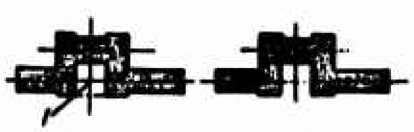
2. In a gear, prepared by cutting from a rod (Fig. 3a), normal stresses in the teeth 1 will be directed unsuitably – across the fibers.



a) b) c)
Fig. 3.

On stamping of a gear from a band (Fig. 3b) the fiber in different teeth will be oriented in the direction of normal stresses unequally: tooth 1 works along the fibers (regular), tooth 2 – across fibers (incorrectly). On manufacture of a gear by upsetting (Fig. 3c) the most favorable location of fibers is obtained especially if the teeth are formed by means of knurling (fiber will not be severed).

3. Crankshaft (Fig. 4a) is forged without a crank neck; the neck and jaws are formed by means of cutting of lap 1. As a result the fibers are severed, and the jaws work across the fibers. During manufacture of a shaft by means of bending (Fig. 4b), the direction of the fibers corresponds to normal stresses in the part.



a) b)
Fig. 4.

Thermal Conditions of Forging and Drop Forging [16], [31]

Temperature interval of forging and drop forging. Forging and hot stamping it is necessary to carry out at temperatures, ensuring

recrystallization of metal in the process of treatment. Full recrystallization of metal in process of treatment. Full recrystallization under usual conditions of treatment by pressure practically occurs at temperatures higher than 0.7 $T_{пл}$, where $T_{пл}$ is the absolute temperature at the beginning of melting. Forging and stamping, accompanied only partial recrystallization, lead in most cases to formation of nonuniform structure that hampers the actual process of deformation. Fullness of recrystallization depends not only on temperature, but also on the speed of deformation. Increase of speed of deformation hampers recrystallization [11].

For every alloy there is established a maximum allowable temperature of heating and an optimum temperature of end of forging (Tables 1 and 2).

Heating to higher temperature evokes overripening, determining coarse-grained structure of forging. On heating to a temperature, close to the temperature of fusing, we get overburning, connected with full loss of plasticity and leading to incorrigible spoilage.

Continuation of forging at a temperature lower than optimum for end of forging leads to work hardening of soft metal, but in hard metal causes crack. Termination of forging at temperatures, significantly exceeding optimum, leads to growth of grain.

Condition and methods of heating. Heating is carried out in hearths, furnaces, and also by electrical current.

During heating it is necessary to ensure: a) required temperature of preparation with maximum uniformity of heating by section and length: b) preservation of integrity of metal; c) minimum decarbonizing of the surface layer and least departure of metal to cinder (waste).

Table 1. Temperature Intervals of Forging and Stamping if Carbon and Alloy Steels [31]

Brand of Steel	Temperature in °C	
	beginning of forging maximum	end of forging minimum
10, 15	1300	700
20, 25, 30, 35	1280	720
40, 45, 50	1260	760
55, 60	1240	760
65, 70	1220	770
15G, 20G, 30G	1250	750
40G, 50G	1220	760
60G, 65G	1200	760
10G2, 30G2, 35G2	1220	750
40G2, 45G2, 50G2	1200	800
15Kh, 20Kh, 30Kh, 15KhA, 20KhA, 30KhA	1250	760
35Kh, 38KhA, 40KhA	1230	780
45Kh, 50Kh, 45KhA, 50KhA	1200	800
25N, 30N, 25NA, 30NA	1240	750
12MA, 15M	1260	780
20M, 30M, 20MA, 30MA	1230	800
40KhG, 40KhGA	1200	770
20KhF, 20KhFA, 40KhFA	1240	760
50KhFA	1200	770
33KhS, 33KhSA	1240	760
37KhS (40SKh), 40KhS, 40KhSA	1200	800
20KhM, 20KhMA	1230	830
30KhM, 35KhM, 30KhMA, 35KhMA	1220	830
27SG, 35SG	1260	780
20KhN, 20KhNA	1250	780
40KhN, 40KhNA, 45KhN, 50KhN	1200	780
12KhN2, 12KhN3, 12KhN2A, 12KhN3A, 20KhN3A	1200	760
30KhN3, 30KhN3A, 37KhN3A	1180	800
12Kh2N4, 12Kh2N4A	1200	800
20KhGS, 25KhGS, 20KhGSA, 25KhGSA	1200	800
30KhGS, 35KhGS, 30KhGSA, 35KhGSA	1180	800
38KhMYuA, 35KhMFA	1180	830
18KhNVA, 25KhNVA	1200	800
33KhN3Ma, 40KhNMA, 30KhN2MFA, 45KhNMFA	1180	800
ShKh6, ShKh9	1200	850
ShKh15	1180	830
1Kh13, 2Kh13, 3Kh13	1180	850
Kh17, Kh25	1120	720
1Kh18N9	1200	870
Kh9S2, Kh5M	1200	850
1Kh18N9T	1180	870
Kh10S2M	1180	850
4Kh14N14V2M	1160	870

Table 2. Temperature Intervals of Forging and Stamping of Certain Nonferrous Alloys [31]

Brand	Temperature in °C	
	beginning of forging	end of forging
Aluminum alloys		
AMts, AMg.......	510	380
D1, D1P.........	500	380
D6, D16, D16P...	460	380
AK2.............	500	380
AK4.............	500	350
AK4-1, AK8......	475	380
Magnesium		
MA1.............	430	300
MA2.............	420	350
MA3.............	370	340
MA5.............	370	320
Brasses		
M (technical copper).........	1000	800
L90.............	900	700
L70, L68........	800	650
L62, LAN, 59-3-2	800	600
LMts, 58-2......	750	550
LO62-1, LS59-1..	800	650
LS64-2..........	850	700
Bronze		
Br. OF6.5-0.15..	900	780
Br. OTs4-3......	920	800
Br. AMts9-2.....	950	850
Br. AZh9-4......	900	700
Br. AZhMts10-3-1.5.............	900	750
Br. AZhN10-4-4..	900	800
Br. KMts3-1.....	770	600
Br. Mts5........	850	750
Br. B2..........	750	650
Br. KN1-3.......	950	800
Titanium alloys		
VT3.............	1050	850
VT3-1...........	1050	800
VT5.............	1100	800
VT6.............	1000	800
VT8.............	1100	850

Speed of heating of procurements in ardent furnaces to a given temperature depends on temperature of the hearth, method of stacking of billets on the hearth (single, close, on support and so forth), dimension and configuration of billets physical properties of metal (thermal diffusivity $a = \frac{\lambda}{c\gamma}$, where λ is thermal conductivity; c is heat capacity; γ is specific gravity).

The more temperature difference between the operating area of the furnace and the surface of the billet, the higher the temperature gradient with respect to the billet cross section. The last-mentioned increase with a decrease in temperature diffusibility of the metal and increase of section of the heated billet.

The temperature gradient determines the appearance of thermal stresses, which, especially in the presence of residual stresses in a cold billet in the first period of its heating (i.e., to the transition through interval of structural transformations Ac_1 - Ac_3) can lead to the appearance of micro- and macrocracks. In small billets from structural steel up to 100-150 mm in diameter these phenomena are not observed during rapid heating. Such billets may be put in a furnace with an operating temperature of 100-150°C higher than the necessary final temperature of heating.

Cold billets from alloy steels with low temperature diffusibility and also cold large billets and ingots of steel of all brands require observance of the permissible rate of heating. The temperature of the furnace during fitting of the billet in this case should be lower than the temperature of forging, and heating is carried out by means of gradual increase of temperature of the furnace or advance of the billets into zones of higher temperatures (methodical furnaces); the first period of heating should constitute 60-70% of its entire duration. The second period of heating, i.e., from the

critical temperature to forging, one should conduct with possibly a higher rate in avoidance of intensive growth of grain, decarbonizing of surface and formation of cinder.

The duration of heating in the furnace for steel billets, in diameter (side of square) up to 200 mm, is shown in Table 3. For cold billets of large dimensions and ingots the permissible duration of heating may be tentatively determined by the formula of N. N. Dobrokhotov

$$t = \alpha k D \sqrt{D},$$

where t is the full (with delays) duration of heating in hours; D is the diameter of the billet in meters; k is the coefficient which is equal to for carbon and low-alloy steels ~10, and for high-alloy ~20; α is the coefficient, depending on the density of stacking of ingots in the hearth of the furnace, taken as 1-1.8 (large values for tight stacking).

For heating of small billets (diameter less than 100 mm) in big-serial and mass production high-speed heating may be used in special mechanized gas furnaces with temperature of operating space of 1400-1500°C. The duration of heating in such furnaces is 2-2.5 times less than in the usual ones.

Heating in electrical resistance furnaces is recommended for magnesium, aluminum and copper alloys. For these alloys a furnace is used with metallic heaters, ensuring an operating temperature up to 900-950°C. Aluminum and copper alloys may be heat also in gas reverboratory furnaces.

Table 3. Time of Heating of Billets from Construction Carbon and Low-Alloy Steels (at a Temperature of Operational Space of the Furnace of 1300°C) in Minutes [31]

Diameter d or side of a square in mm	Profile of billet: Round — Arrangement of billets in furnace: single	Round: at distance d	Round: at distance $\frac{d}{2}$	Round: close	Square: single	Square: at distance a	Square: at distance $\frac{a}{2}$	Square: close
Heating from 15 to 1200°C								
10	2	2	3	4	2.5	3.5	4.5	8
20	3	3.5	5	7	4.5	6	8	13
30	5	5.5	7	10	6	8.5	11	19
40	6.5	8.0	9.5	13	8	11	14	25
50	8	9.5	12	16	10.5	14.5	17.5	32
60	10	11.5	14	19.5	12.5	17.5	21	38
70	12	13.5	16.5	22.5	14.5	20.5	25	44
80	14	15.5	19.5	26	17	23.5	29.5	52
90	16	18.5	23	31	19.5	27	33.5	62
100	18	21.5	27	35	23	32.5	40	72
110	20	24	27	40	26	36.5	41	80
120	22.5	27	30	46	29.5	41.5	45	90
140	27.5	33	36.5	55	35	50.5	55	110
160	33	39.5	44	66	43	60	69	132
180	39.5	47.5	52	79	51.5	72	81	158
200	46	55	61	92	60	84	96	184
Heating from 700 to 1200°C								
10	1	1	1.5	3	1.5	3	2	4
20	2	2.5	3	4	3	4	4.5	9
30	3	3.5	3.5	6	4	5	6	12
40	4	5	5	8	5	7	8	16
50	5	6	6.5	10	6.5	9	10	20
60	6	7	8	13	8	11	13	24
70	7.5	9	10	15	10	13	15.5	29
80	9	10.5	12	18	12	16	18	35
90	11	13	14	22	44	19	21.5	43
100	13	15.5	17	26	17	22	26	52
110	14.5	17.5	19.5	29	19	26.5	30	58
120	16.5	19.5	21.5	33	21.5	30	34.5	60
140	20	21	26.5	40	26	36.5	42	80
160	24	27	32	48	31	43.5	50	96
180	28.6	34.5	39	57	37	52	60	114
200	33.5	40	44	67	48	61	70	134

NOTES: 1. For carbon tool and medium-alloy steels the tabular time of heating is increased by 25-50%, for high-alloy steels, by 50-100%.

2. For calculation of the influence of length l of the billet, the tabular time of heating is multiplied by the following coefficients K depending upon the ratio of length l of the billet to the linear dimension of section d or a:

$\frac{l}{d}$, $\frac{l}{a} \geq 3$	2	1.5	1
K 1	0.98	0.92	0.71

For heating of steel billets to forging temperature high-temperature electrical furnaces of type Г and ОКБ with carborundum heaters (silit, globar) of the trust "Electric furnace" may be used. However using them is suitable only under laboratory conditions or for a very small volume of production and specially high requirements on quality of heating, and also for non-scale heating in a protective atmosphere.

Electrical (induction and contact) heating [31] has essential advantages over heating in furnaces: a) high speed of heating; b) convenience of adjustment of temperature of heating; c) insignificant waste of metal; d) possibility of automation of supply and output of billets with time control; e) possibility of increase of temperature of beginning of forging without appearance of overheating; f) improvement of conditions of labor; g) constant readiness of installation for starting; h) possibility of combination of heating unit in one aggregate with the forging machine.

Induction heating is carried out by currents of industrial and heightened frequency. Correspondence of selected frequency of current to diameter of heated billet (Table 4) ensures minimum expenditure of electric power (for steel 400-500 kw/hr per 1 m of heated metal). For billets in diameter more than 50-60 mm it is expedient to have combined heating at two frequencies up to the Curie point at industrial frequency and then to forging temperature at an increased frequency.

Heaters (inductors) under conditions of mass and large-scale production which are expedient are the methodical type with simultaneous heating of several billets located one behind the other along the axis of the inductor. The number of billets n simultaneously in the inductor may be determined from the expression

$$n = \frac{T}{t},$$

where T is time of heating in min; t is necessary rate of output in minutes. With an increase in the ratio $\frac{D_u}{D_3}$ (where D_u is the diameter of the inductor; D_3 is the diameter of the heated billet) the efficiency of the inductor sharply drops. Therefore it is desirable to abserve $\frac{D_u}{D_3} \leq 1.6\text{-}1.8$ for billets up to 50 mm in diameter $\frac{D_u}{D_3} \leq 1.2\text{-}1.4$ for billets greater than 50 mm in diameter.

Table 4. Frequency of Current and Time of Heating of Steel Billets [20]

Diameter of billet in mm	Recommended frequencies of current in cps					Time of heating in minutes at frequency of current in cps				
						50	500	1000	2500	8000
20	–	–	–	–	8000	–	–	–	–	0.4
30	–	–	–	2500	8000	–	–	–	0.6	0.8
40	–	–	–	2500	8000	–	–	–	1.0	1.4
50	–	–	1000	2500	8000	–	–	1.4	1.8	2.0
60	–	–	1000	2500	–	–	–	2.0	2.3	–
70	–	500	1000	2500	–	–	2.6	2.8	3.0	–
80	–	500	1000	2500	–	–	3.2	3.6	4.0	–
90	–	500	1000	–	–	–	4.2	4.6	5.0	–
100	–	500	1000	–	–	–	5.5	6.0	–	–
110	–	500	1000	–	–	–	7.0	7.5	–	–
120	–	500	1000	–	–	–	8.5	9.0	–	–
150	50	500	1000	–	–	12.0	14.0	16.0	–	–
175	50	500	1000	–	–	15.0	18.0	–	–	–
200	50	500	1000	–	–	20.0	25.0	–	–	–

Contact electric heating (at the expense of liberation of heat as a result of ohmic resistance of the billet included in the current circuit) is very convenient for long round billets up to 70 mm (Table 5) in diameter. Installations for contact heating are simpler and require smaller capital expenditures than for induction heating. Expenditure of electric power constitutes 350-450 kw/hr per 1 meter of heated steels.

Non-scale heating. Sharp lowering of waste (to fractions of a percent) and decarbonizing is possible by application of high-speed heating, especially electric heating (induction and contact).

Table 5. Specific Power, Compression and Duration of Contact Heating [31]

Indices	Diameter of billet in mm				
	20	30	40	50	60
Average specific linear power in kw/cm..........	1.7	1.9	2.1	2.3	2.5
Compression of contacts in meters...............	1	1	3	3	3
Tentative time of heating in minutes...........	0.2	0.4	0.7	1.0	1.3

Completely non-scale heating is possible in protective atmospheres and in products of incomplete combustion (introduced).

Condition of cooling of forgings. Cooling too fast leads to the formation of external and internal cracks as a result of thermal stresses. The lower the temperature diffusibility of the metal and the larger the forging, the slower cooling should be carried out.

In increasing order of duration of cooling we have [16]: in air (carbon construction steel), in piles (for instance, chromium, nickel steel type 15Kh-30Kh, 25N, 30N with maximum transverse dimension of section of forging above 150 mm), in pits (for instance, alloy steel type 40Kh-50Kh, 40KhG, 20KhGS and so forth with dimension of section above 150 mm), with a furnace (for instance, alloy steel type Kh2N4MA, 18KhNVA, 20Kh2N4A etc. with section above 150 mm, tool alloy steel with cross section above 100 mm).

Technological Methods of Obtaining Forgings

Methods of obtaining forgings may basically be subdivided into three groups: forging, stamping and specialized processes.

Table [illegible]. The Most Wide-Spread Methods of Obtaining Forgings and Their Tentative Characteristics

Methods of obtaining	Tentative Characteristic of obtained forgings	Machining Allowances, size tolerances and cleanness of surface	Applicability	Chiefly utilized equipment
Forging (see p. 92).	Forgings by weight approximately to 250 m of relatively simple form, frequently with allowances for simplification of form as compared to ready part. Require significant treatment by cutting, usually around. Indication on construction, see Table 9.	Maximum machining allowances and size tolerance in hammer forging by All-Union Government Standard 7829-5[illegible], in press forging by All-Union Government Standard 7062-54. Machining allowances and size tolerances (with respect to transverse dimensions) depending upon dimensions and form of forging: in hammer forging from 5 ± 1/2 to 34 ± 10 mm, in press forgings from 16 ± 6 to 90 ± 36. For unprocessed forgings or sections the magnitude of deviations may be lowered by 20-50%. Cleanness of surface is usually up to ∇ 1.	In piece and small-lot production.	Forging hammers with weight of incident parts: steam – 1-5 m, pneumatic 75-1000 kilogram. Forging hydraulic presses with force of 500-5000 m and more to 30,000 m (Tables 7 and 8).
With application of a special tool (see p. 106).	The same, but with smaller allowances.			
In underlaid dies open and closed (see p. 106).	Forgings by weight approximately up to 150 kg, mainly smaller (for instance, to 50 kg). Possibly preparation without allowances of forgings of complicated forms usually from a preliminarily forged blank.	Allowances approximately from 3 mm and above, tolerances from $^{+1.5}_{-0.5}$ mm and more. Cleanness of surface to ∇3.	In small-lot production, for instance, or lots of over 50-200 pieces	The same
Stamping in open dies (see p. 107).	The most widely used method. Forgings by weight from several grams approximately to 3 m (basic mass – to 50-100 kg) of very different and complicated forms, significantly close to forms of ready parts; execution of depressions or holes in lateral walls is impossible. Treatment by cutting, as a rule, only with respect to abutting surfaces with other parts; sometimes it is completely removed by sizing (by a clinching iron). Model forgings are shown in Fig. 30, construction indices – in Table 21.	Maximum allowances and tolerances by All-Union Government Standard 7505-57. Allowances to the side for hammer forgings by weight to 40 kg with dimensions to 800 mm depending upon class of accuracy – from 0.6-1.2 to 3.3-6.4. For forgings, stamped on crank hot-stamping presses, allowances are 0.1-0.2 mm less. Allowances see Table 12. Cleanness of surface ∇1-∇4. With cold sizing (clinching) allowances are lowered to ±0.1-±0.25 (calibration of usual accuracy) and to ±0.05-±0.15	In serial and big-serial production; in particular cases it may be profitable for lots of over 200-500 pieces	Crank hot-stamping presses with a force of 630-10,000 m; stamping hammers with weight of incident parts: double action steam 0.5-35 m; counter-blow (equivalent) to 60 m; simple action steam, frictional with board, chain correspondingly to 10; 5 and 8 m; frictional screw pressed with a force of 40- 2000 m; hydraulic forging presses with a force of up to ~70,000 tons (Tables 13 and 14).

Table 6 (Continued)

Methods of obtaining	Tentative Characteristic of obtained forgings	Machining Allowances, size tolerances and cleanness of surface	Applicability	Chiefly utilized equipment
		(calibration of higher precision). Surface quality is increased to ∇4-∇6, and even to ∇8.		
Stamping in closed dies (see p. 128).	Forgings by weight approximately to 100 kg (mainly to 15 kg), simple form (Fig. 41), chiefly in the form of solids of revolution or close to them. Especially recommended for stamping of alloys with limited plasticity.	The same	The same	The same
Melting and piercing (see p.129).	Forgings by weight approximately to 75 kg, constituting (Fig. 43): a) round, conical or step, and also shaped section rod with a relatively massive head of different form, including a complex one; b) forging of bushing type with deep cap or perforation carity and one-sided flange or other thickening, including a complicated form.	Allowances and tolerances on dimensions of sections, obtained by pressing: a) external diameters (5-150 mm) from $0.4^{+0.3}_{-0.1}$ to $1.6^{+0.7}_{-0.3}$ mm; b) diameters of cavities (10-100 mm) from $1.6^{+0.3}_{-1.0}$ to $5.0^{+0.5}_{-1.5}$. Cleanness of surface ∇2-∇5.		Crank hot-stamping, frictional screw and hydraulic presses.
Stamping in dies with split matrices (see p. 131).	Forgings (especially from nonferrous alloys) weight approximately to 150 kg (mainly smaller) of complicated form, for instance, with holes in lateral walls, impracticable without allowances by other methods (Fig. 48).	Analogous to stamping in open dies, but tolerances somewhat larger in the direction of disassembling of parts of the die.	In the absence of automation of disassembling of matrices — in small-lot production; with automation and on special machines — in serial and big-serial production.	The same, special machines.
on horizontal forging machines (see p.132).	Forgings (Fig. 52) of weight approximately to 30 kg chiefly in the form of rods with heads or thickenings of different form, including with holes, and also hollow forgings with perforation or cap holes, flanges and protrusions. Construction indices may be seen in Table 25.	Maximum allowances and tolerances by All-Union Government Standard 7505-57. Magnitude of allowances if 40-45% larger than for hammer forgings, basic tolerances are fixed the same (see Table 16). Cleanness of surface ∇1-∇4.	The same as stamping in open dies but, profitable at relatively large seriality.	Horizontal forging machines with a force of 100-4000 m (Table 24).
Stamping of a bend (see p.138).	Forgings of parts (Fig. 54), having bent form in one or several planes, obtained mainly from rolling of different profiles, but sometimes from a stamped blank.	Depending upon initial blank. As a result of bending distortions occur in sections of angles turned by a small radius.	In serial and large scale production.	Horizontal bending machines (bulldozers) with a force of 15-500 m, crank presses.
Stamping, rolling (see p.138).	Forgings by weight approximately to 1-2 kg both relatively simple form — a type of metalworking tool (Fig. 57), and quite	Allowances analogous to hammer forging, field of tolerance by length of forging 1-3 mm, by height and width	In big-serial production (productivity 1000-5000 forgings per hour).	Forging rollers with a diameter of rollers of 300-1000 mm.

Table 6 (Continued)

Methods of obtaining	Tentative characteristic of obtained forgings	Machining allowances, size tolerances and cleanness of surface	Applicability	Chiefly utilized equipment
	complicated (Fig. 58): connecting rods, cams, links of a transporter, turbine blades.	0.5-1.0 mm. Cleanness of surface is ∇1-∇4.		
Specialized processes pressing on rotary-forging machines (see p. 139).	Depending upon the type of machines used, solid and hollow straight forgings (Fig. 60) of prolongated step form in the shape of solids of revolution with cylindrical or conical sections (stepped shafts, sewing needles, spindles, pins), and also stepped or forgings or forgings with taperings of square or rectangular cross section.	Allowance (in case of need) on grinding. Field of tolerance during cole pressing (blank is rods of diameter up to 20 mm) within limits 0.02-0.10; for hot, 0.2-0.6. Cleanness of surface during cold pressing ∇9-∇10, for hot – to ∇6.	In big-serial production (productivity of 100-600 forgings per hour).	Rotary-forging machines for pressing of rods from 5 to 80 mm.
reeling (see p. 140).	Forgings of heightened accuracy chiefly of the ring type (Fig. 62), including complicated sections, diameter 70-700 mm with a height of 20-180 mm (rings of ballbearings, ringspinning frame and so forth).	Field of tolerance for forgings of rings of ball-bearings of diameter 80-700 mm by external diameter and height 1-6 mm by inside diameter 1.5-2 times more.	In big-serial production (productivity 75-500 forgings per hour depending upon dimension).	Rolling machines for rings of diameter to 700 mm.
Rolling of teeth (see p. 141).	Obtaining of teeth with modulus to 10 mm of cylindrical, conical and chevron toothed wheels with diameter to 600 mm.	For hot knurling (for m > 2.5 mm) accuracy of the 3-4th class; cleanness of surface ∇5-∇6; for cold knurling ∇7-∇8.	In big-serial production (productivity 60-1000 pieces per hour depending upon modulus and diameter).	Gear knurling mills vertical and horizontal.
Transverse rolling (see p. 141).	Forgings of prolongated form of stepped shaft type and also bushings (Fig. 63).	Allowances and tolerances somewhat less than for stamping.	In big-serial and mass production (productivity 10-35 thousand m in a year).	Three-roller mills with conical or disk rollers; two-roll mills with screw gauges.
Combined processes (see p. 141).	Forgings with respect to form requiring applications of various methods for obtaining of separate sections (Fig. 64).	Depending upon combination of applied methods.	In big-serial production.	Combinations of different machines; for instance, hammer (or press) and horizontal-forging machine or horizontal bending machine and so forth allowances underlie removal of treatment by cutting and so forth.

A characteristic peculiarity of forging is the use for manufacture of different pieces of a chiefly universal tool. For stamping, conversely, it is necessary to use a special tool. Each of the specialized processes is useful for a limited nomenclature of pieces or, even, of one definite one of the category and requires use of not only a special tool, but also special equipment.

For unit and small-lot production, as a rule, forging is more profitable than stamping; for big-serial and mass production stamping is always significantly more profitable.

For average series selection is made on the basis of calculation of primecost of the finished product for each method of manufacture.

Stamping sometimes turns out to be more profitable than forging already for a lot of several tens of details.

The most important methods of obtaining of forgings with tentative characteristics of the latter and other data are given in Table 6.

Forgings

Technological bases of construction of forged parts. To parts, prepared from forgings it is desirable to give the simplest form, limited to flat or cylindrical surfaces, for the purpose of guarantee of minimum waste and labor-consumingness both in the process of forging, and during subsequent treatment by cutting.

It may turn out that separate sections in general, are impracticable by forging, for which forging must be carried out with allowances (Fig. 5) for simplification of form.

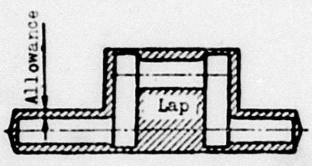


Fig. 5. Forging with allowance.

Certain indications with respect to construction of forged parts and choice of equipments are given in Table 7, 8 and 9.

Table 7. Weight of Ingots (Approximate), Processed on Forging Hydraulic Presses [36]

Force of press in m	Weight of ingots in m	
	Average	The biggest
500	0.65	2
800	2	5.5
1,250	5.5	12
2,000	14	28
3,200	33	58
5,000	63	98
10,000	150	250

Table 8. Weight of Forgings, Obtained on Forging Hammers [36]

Weight of incident parts in m	Weight of forgings in kilograms		
	shaped		smooth shafts
	average	the biggest	the biggest
1	20	70	250
1.5	40	120	350
2	60	180	500
3	100	320	750
4	140	500	1100
5	200	700	1500

Table 9. Indications with Respect to Construction of Parts Prepared by Free Forging

1. To avoid conical a wedge-shaped b forms, especially with small coicity or incline

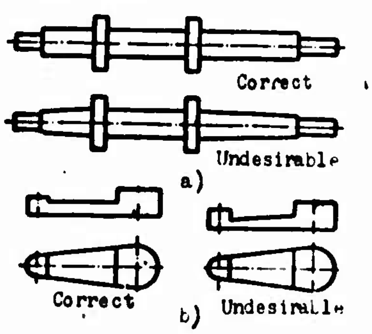
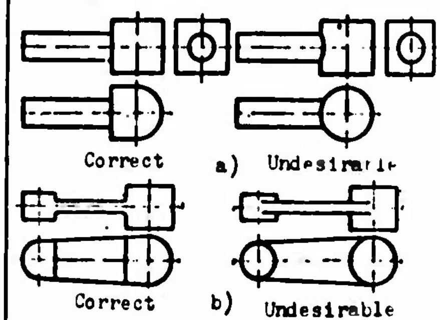
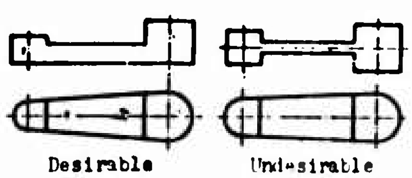


Table 9 (Continued)

2. To avoid mutual intersection of cylindrical surfaces with prismatic sections of parts b



3. It is more preferable to designate one-sides flanges in place of bilateral ones (especially for small parts)



4. To avoid ribbed sections, since ribs in most cases are impossible to prepare by forging, and it is necessary to designate allowances. So-called ribs of rigidity in forgings are impermissible

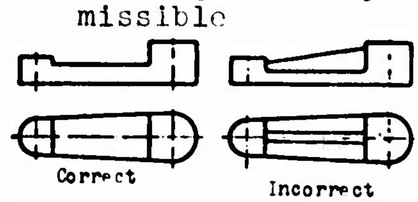
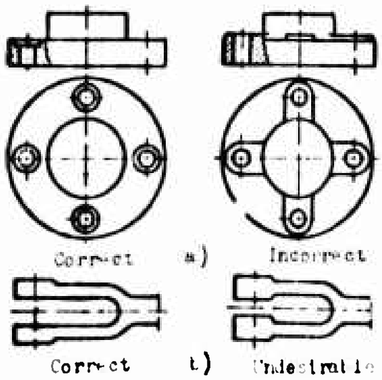


Table 9 (Continued)

5. One should not allow bosses, paying, flanges and so forth on the basic body of forging a, and also inside forks of forked parts b



7. It is very expedient to make parts of complicated shape by welding from several forgings a [25] or welded from forged 1 and poured 2 elements b [26]

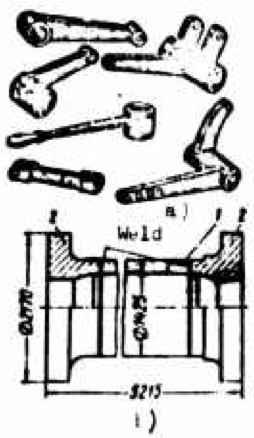
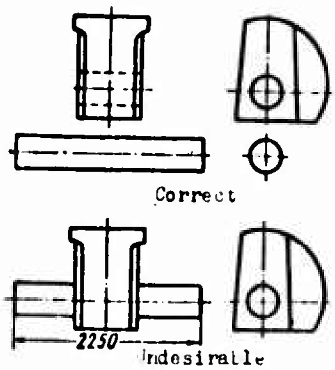
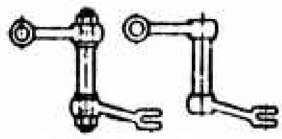


Table 9 (Continued)

6. In possible cases of a part with sharp difference in dimensions of cross sections a or inevitably complicated form b replace by a combination of several fastened simpler forged parts





Weight and dimensions of initial material. Initial material for forgings are ingots and rolled products chiefly of square, strip and round profile, but for nonferrous alloys also pressed rods are used.

<u>The weight of initial material</u> $G_{ис}$ is determined by the formula

$$G_{ис} = G_{пк} + G_{пр} + G_{он} + G_{уг} + G_{об},$$

where $G_{пк}$ is the weight of forging; $G_{пр}$ is the weight of reject from the riser part of the ingot; $G_{дн}$ is the weight of reject from the

bottom part of ingot; G_{yr} is the weight of reject to waste; G_{06} is the weight of reject on cutting off.

The weight of reject from the riser part of usual ingots from construction carbon steel, poured from above with a warming extension, usually makes up 15-25% of the weight of the ingot, but for ingots from construction alloy steels, 25-35%. For tool alloy steels in case of casting without a warming extension departure can constitute 50%.

The weight of the reject from the bottom part of the ingot $G_{ДН}$ makes up for carbon steel 4-7% of the weight of the ingot, but for alloy, 7-10%.

At present new forms of ingots (present new forms of ingots (pro-longated and hollow [25] are gaining popularity which allow decrease in departure from the riser part to 13-15%, and from the bottom, to 3-5% of the weight of the ingot.

Elongated ingots (ratio of length of the middle part to its diameter 4-5) are expediently applied for forgings of propeller shafts, columns, tractions and other long solid forgings.

Hollow ingots with a diameter of axial channel d, determined by the relationship $\frac{D}{4} \leq d \leq \frac{D}{2.6}$, where D is the external diameter of the ingot, are intended for manufacture of hollow forgings of the drum type.

Weight of the rejects to waste G_{yr} is assigned up to 1.5-2.5% of the weight of the heated metal on every heating and up to 1.5% on every preheating. The weight of the rejects on cutting off depends on the complexity of forging, and also on the technological process used. For manufacture of forgings of identical form relatively large rejects are obtained during forging of pieces of smaller weight.

Approximately the weight of the initial material taking into

account waste, including scrap can be determined by the expression

$$G_{uc} = kG_{n\kappa},$$

using experimental values of k (Table 10 and 11).

Table 10. Values of k for Forging on Presses of Big Forgings

Group of forgings	Basic operations, used for forging*	k
Smooth shafts, columns, rods	Drawing, cutting of surpluses, dressing	1.4-1.6
Plates, small plates and cubes	Upsetting, drawing, cutting, finishing	1.5-1.8
Rings, tires, drums	Upsetting, piercing, distribution on mountting, extraction from mandrel	1.6-1.7
Shafts with steps, shafts with flanges	Upsetting (not always), extraction, marking, fullering, chopping of surpluses, dressing	1.6-1.8
Disks	Upsetting, distillation of field, piercing, dressing	1.6-1.9
Crankshafts	Upsetting (notalways), drawing, transmission, twisting (sometimes), dressing, chopping	1.7-2.0

*The operation of fettling of the bottom and riser and stretching of the shank under the chuck are not shown.

Table 11. Values of k During Forging on a Hammer from Piece Measuring Blanks (According to V. V. Kerekeshu)

Group of forgings	Basic operations, applied during forging	k
Fixed flanges round, oval, square; plates, small cubes, short bars	Upsetting, rolling, dressing	1.02-1.03
Flanges with aperture, collars, nuts	Upsetting, forging to dimension, piercing, dressing	1.02-1.03*
Rolling rings, bushings, shell, sleeves	Upsetting, piercing, distribution on a mandrel, dressing	1.03*
Welded rings, bushings, shells, sleeves	Drawing, bending, welding, dressing	1.03-1.05
Smooth shafts, shafts, long bars, square, rectangular, hexahedral	Drawing, jettling, dressing	1.05-1.07
Shafts and shafts with steps or flanges, bolts, keys, runners	Drawing, marking, fullering, fettling, dressing	1.07-1.10
Fixed pinions	Upsetting, rolling, stretching of field, dressing	1.08-1.10
Shafts and shafts with bilateral steps or beads, spindles, pulls, shackles, clamps	Drawing, marking, dressing, fullering	1.10-1.12
Wrenches connecting rods, simple levers	Drawing, marking, fullering, forming of heads, dressing	1.15-1.18
Complicated levers and connecting rods, cranks	Drawing, fettling of heads, trimming, dressing	1.18-1.25
Crankshafts, curved levers, double-arm levers	Drawing, transmission, fettling, dressing	1.25-1.30

*Without waste on core punch during piercing, determined by calculation and added to.

Dimensions of billets. A forged piece is prepared by upsetting. By the weight of the blank (volume $V_{\text{вк}}$) its dimensions are chosen in such a manner that the relationship which follows was maintained

$$1{,}25\, d_{\text{вк}} < h_{\text{вк}} \leq 2{,}5\, d_{\text{вк}},$$

at which $d_{\text{вк}} = (0{,}8 \div 1{,}0)\sqrt[3]{V_{\text{вк}}}$ for round and $d_{\text{вк}} = (0{,}75 \div 0{,}90)\sqrt[3]{V_{\text{вк}}}$ for square blanks.

The length of blank is determined by division of its volume by the area of cross section according to the finally definitized in accordance with sorting (All-Union Government Standard) dimension of cross section.

On selection of a blank of great height for drop forging one should check the technical possibility of upsetting by the formula

$$H - h_{uc} > 0{,}25\, H,$$

where H is the stroke of the ram of the hammer.

During forging by upsetting from an ingot, the latter is chosen by sorting of ingots on the basis of calculated weight of initial material.

Forged piece is prepared by drawing. For forgings, having round, square or cross sections close to these, it is necessary to observe the relationship

$$F_{uc} > yF_{max},$$

where F_{uc} is the area of cross section of the initial material; F_{max} is the area of maximum cross section of the forging; y is the forging ratio (see p.80).

Basic operations of technological process. Basic operations of the technological process of free forging are: 1) upsetting, 2) drawing, 3) piercing, 4) cutting, 5) bending, 6) twisting.

Upsetting is applied: a) for obtaining of forgings (or separate sections of them) with large transverse dimensions for relatively small height (flanges, gears, disks) from blanks of smaller cross section; b) as preliminary operation before piercing during manufacture of hollow forgings (rings, drums); c) as preliminary operation for increase of quality of transverse samples; d) for increase of forging ratio during subsequent drawing.

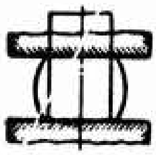


Fig. 6.

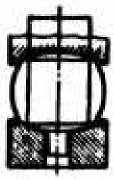


Fig. 7.

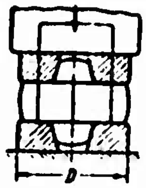


Fig. 8.

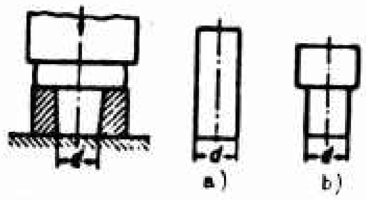


Fig. 9.

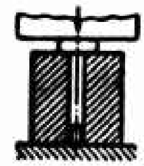


Fig. 10.

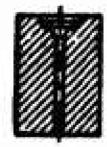


Fig. 11.

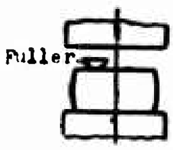


Fig. 12.

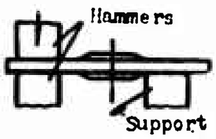


Fig. 13.

Upsetting of a cylindrical blank from an ingot without a shank (Fig. 6) is used for working under a hammer and also under a press when the following operation is piercing; upsetting of a blank with a shank (Fig. 7), during working under a press, when the following operation is drawing. In the last case underlaid plates are used from which the lower one has a hole under the shank of the blank.

By upsetting on plates with holes (in underlaid rings) (Fig. 8) we obtain a part of the fixed pinion type, flanges and disks with bosses, where for relatively small diameters of the bosses, the volume of the part is comparatively large, and stretching of ends of the blank to the diameter of the bosses for any reasons is undesirable or is impossible (for instance, in view of the small height of the bosses). If the diameter of the blank may be selected equal to or somewhat smaller than the diameter of the boss (Fig. 9a) or the end of the blank may be preliminarily drawn to this dimension (Fig. 9b), then upsetting in a ring is used.

By upsetting in the bottom part (die) flanges and heads on long rods (Fig. 10 and 11) are obtained.

Upsetting by distillation is used for decrease of height and increase of diameter of an already snubbed blank, when it is impossible to have further upsetting by direct blows of a hammer (pressing) on its entire surface due to high resistance to deformation. Distillation is

done with the help of reeling (Fig. 12) or for large diameters of the forgings (for instance, turbine disks) directly by hammer blocks (Fig. 13).

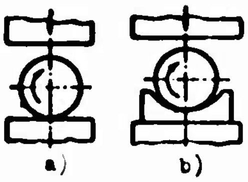


Fig. 14. Diagram of burnishing along the diameter: a) by hammer blocks; b) in swages.

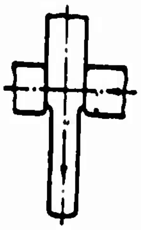


Fig. 15.

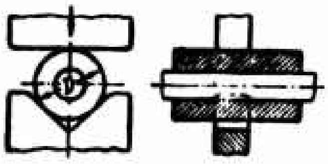


Fig. 16.

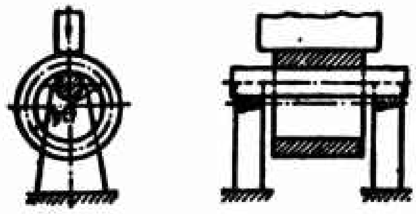


Fig. 17.

The finishing operation after upsetting is burnishing with respect to diameter (Fig. 14).

Drawing (hot drawing) (Fig. 15) is used for increase of length of the initial blank at the expense of reduction in area of its cross section (shafts, stepped shafts, beams, connecting rods and others). Basic varieties of operation of drawing are the following.

Drawing with straightening (Fig. 16) – increase of length of the hollow blank at the expense of decrease of thickness of its walls (forging of artillery barrels, boiler drums, turbine rotors, etc).

Distribution on a mandrel (Fig. 17) – simultaneous increase in external and internal diameters of a hollow blank at the expense of decrease of thickness of its walls (forging of rings, shells, drums and so forth).

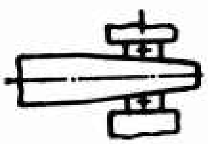


Fig. 18.

Drawing into a cone is carried out with the help of wedge-shaped fullers (Fig. 18).

Piercing (Fig. 19 and 20) is used for obtaining of transverse holes in blanks or depressions.

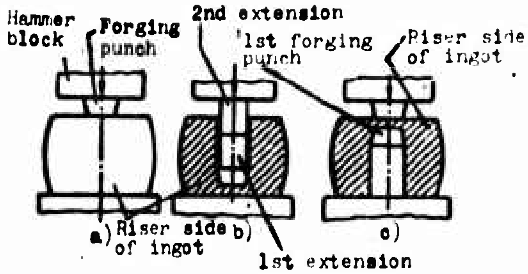


Fig. 19. Diagram of piercing without an underlaid ring: a) beginning of operation; b) end of first stage; c) beginning of second stage.

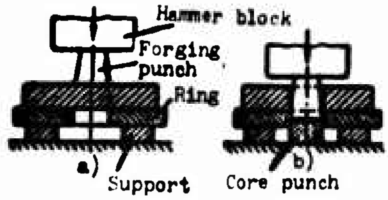


Fig. 20. Diagram of piercing with an underlaid ring: a) beginning of operation; b) end of operation.

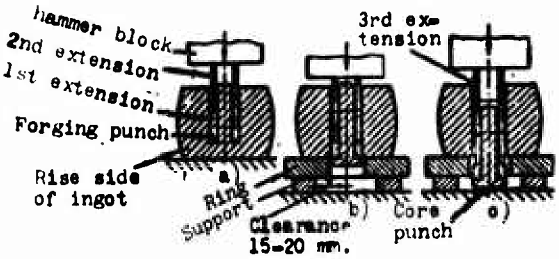


Fig. 21. Diagram of punching using a coring punch: a) first stage; b) second stage; c) end of operation.

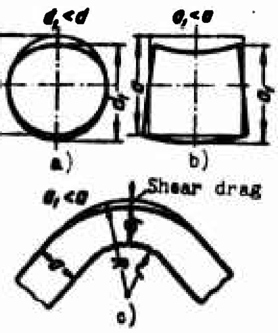


Fig. 22. Distortion of shape of a blank during bending: a) round cross section; b) rectangular cross section; c) shear drag.

Piercing is accompanied by distortion of the form of the blank, and during transverse piercing there is also waste metal in core punch.

A hole of large diameter (over 500 mm) is punched using hollow forging punches [coring punches] (Fig. 21).

Chopping is used for removal of surpluses on the ends of forgings, and also of the bottom and riser parts of ingots and obtaining of figured forgings (crankshafts with stamped elbows, shafts, forks and so forth).

Bending is used for obtaining directly or in combination with other operations of various articles of bent shape (angles, clamps, hooks, brackets and so forth). The operation of bending is accompanied by distortion of the initial shape of the cross section of the blank and a decrease in its area (shear drag) in the zone of the bend (Fig. 22).

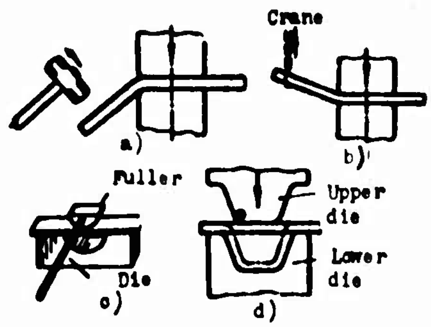


Fig. 23. Diagram of methods of bending: a) sledge hammer; b) crane; c) with lower die and fullering; d) in a die.

Furthermore, it is possible to form folds along the internal contour and cracks along the external one. These defects are the more probable the smaller the radius of curvature and the greater the angle of bend. In order to remove distortion of shape of the cross section of the blank in the zone of bending, dressing (ironing) with the help of smoothers, fullers and hammer blocks is carried out. Shear drag is not removed by dressing. For obtaining in the zone of bending a cross section of desirable area, in this place increased transverse dimensions are given the blank in advance. Some methods of bending are shown in Fig. 23.

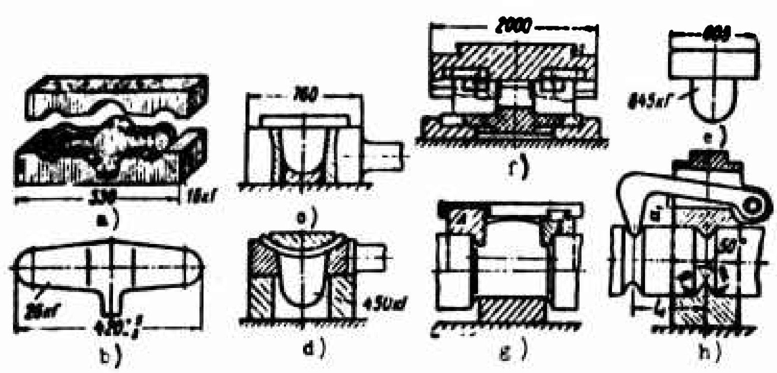


Fig. 24. Examples of a special tool [12], [25], [26]: a) tool for forging of rocker arm; b) forging of rocker arm, obtained without application of a special tool; c) and d) tool for forging of a runner; e) forging of a runner obtained without application of a special tool; f) tool for forging of disks with a hub: upper slide hammer block and lower ring with shift inserts; g) attachment for transmission; h) attachment for fullering.

Twisting is used for obtaining of forgings of special shape (crankshafts with elbows, located in different planes, wall bolts, stanchions for fences, spiral drills, etc.).

Application of special tool and underlaid dies. Approximations of form of a forging to the form of the finished part and lowering of allowances and tolerances may be attained by using during forging in addition to a universal tool also a special tool. In view of significant reduction of expenditure of metal, increase of productivity

of forging and decrease of volume of treatment by cutting, application of a special tool (Fig. 24) is usually profitable even in small-lot production [12], [25], [26].

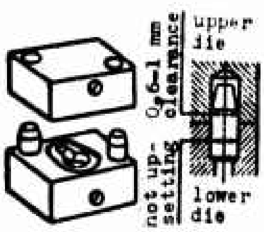


Fig. 25.

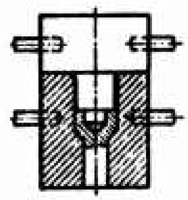


Fig. 26.

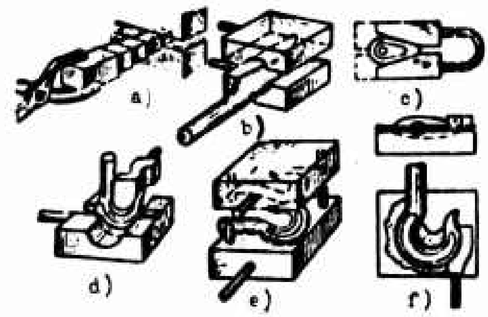


Fig. 27. Technological process of manufacture of forging of a hook [31]: a) streching of the end into a cone; b) rolling of the end into a conical swage, burnishing of the cylindrical end in a separate swage; c) transverse pressing of the blank into a wedge-shaped section; d) bending with the help of the bottom part and a semicircular cover plate; e) stamping in an underlaid die, f) removal of a projecting edge with the help of a bent square.

A further development of a special tool is underlaid dies – open (Fig. 25) and closed (Fig. 26), allowing molding not only of separate surfaces (as for example, the tool in Fig. 24a), but also of complicated sections of forging or the entire forging as a whole on forging equipment. Preliminary operations are done by forging using a universal tool and sometimes also a special tool. Application of underlaid dies reduces the expenditure of metal, increases productivity of forging and decreases the volume of treatment by removal of shavings. An example of the technological process of forging with application of underlaid dies is shown in Fig. 27.

Combined forging – stamping. On the basis of the process of combined forging – stamping (proposed by A. V. Potekhin) the principle is founded of separation of complicated technological process of manufacture of forgings into separate simple operations, executed in definite sequence in quick-change pass-inserts (Fig. 28), secured in universal forging attachments (blocks), which are installed in a

crank press [3].

Combined forging – stamping by the method of A. V. Potekhin is applicable under conditions of small-lot production, for instance for monthly lots of less than 50 forgings weighing up to 35 to 100 kg (for a press with a force of 600 m). Basic advantages of the given method consist in economy of metal at the expense of decrease of laps, allowances and tolerances (to ±0.5-±0.2) and in significant increase of productivity of labor.

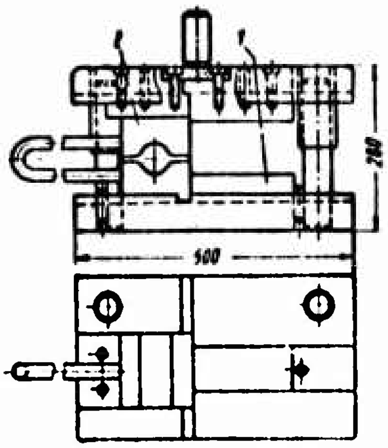


Fig. 28. Universal attachment for forging by drawing of stepped forgings [3]: 1 – shift hammer blocks; 2 – shift swages (or a pair of other hammer blocks).

Stamping in Open Dies

A peculiarity of stamping in open dies giving a forging final form is flowing of metal to the sides, beyond the limits of the cavity of the figure of the die accompanying filling of it by the metal. As a result, in the forging along the line of disassembly will be formed an annular projecting edge ("burr") (Fig. 29), for which in dies a special cavity – groove is anticipated. In most cases it is necessary to prepare the initial blank for the purpose of approximation of its form to the form of the ready forging. This preparation is small-lot production may be carried out by forging; in serial production it is done chiefly with the help of forging (and also preliminary) dies.

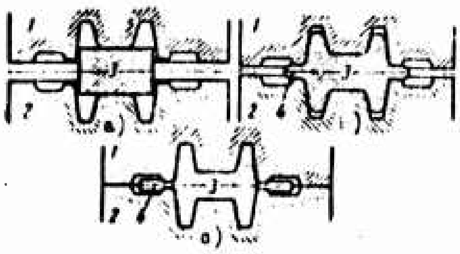


Fig. 29. Diagram of formation of a burr: a) initial moment of stamping; b) intermediate phase – beginning of formation of the burr; c) final moment of stamping; 1 – upper die; 2 – lower die; 3 – stamped blank; 4 – burr.

All necessary cavities and working for consecutive form-change of blank (including also obtaining of final form) are called passes. The latter can be carried out in one die block (or are fixed in one holder), forming a multipass die. Stamping in multipass dies is the most wide-spread.

However under conditions of big-serial and mass production the process of stamping may be broken down distributing separate transitions or groups of transitions among various machines. Thus, process of stamping is carried out, for instance, on several hammers, on a horizontal forging machine and hammer (press), on forging rollers and a hammer (press) and so forth. Preliminary facing of the blank, in particular by means of rolling, before stamping of forgings with a sharp difference in cross sections on a crank hot-stamping or screw usually is necessary (see p.120), and before stamping on a hammer very desirable. Significant simplification of the process of stamping with simultaneous increase of productivity and reduction of expenditure of metal is possible to attain by using as the initial material periodic rolled products of variable cross section prepared in a metallurgical plant on a longitudinal rolling mill or periodic rolled products, obtained from a transverse rolling mill.

Approximate forms of forgings are presented in Fig. 30. Accuracy is characterized in Table 12, and data on selection of equipment and its productivity are given in Tables 13 and 14.

Technological bases of construction of forgings, stamped in open dies on hammers and presses. Selection of the surface of disassembly. Depending upon the complexity of shape of a part (forging) disassembly of the die is done along a plane or other more complicated surface.

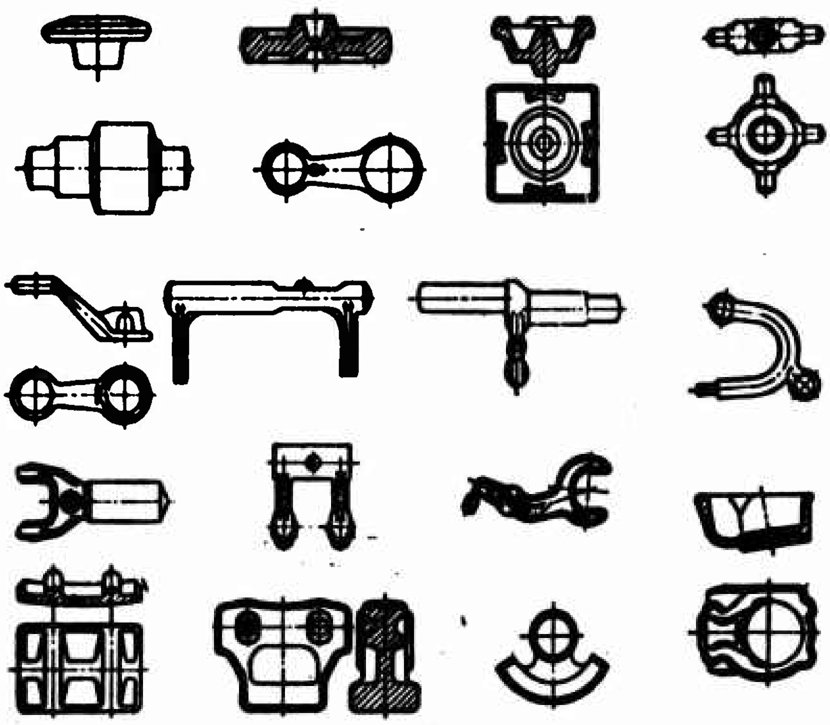
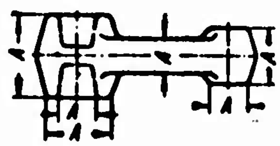


Fig. 30. Examples of some shapes of forgings stamped in open dies.

Table 12. Allowances on Dimensions, Depending on Incompleteness of Stamping or Bilateral Wear of Dies, for Forgings of the 1st Group of Accuracy in mm (All-Union Government Standard 7505-55)



Weight of forging in kg.		Dimensions of A in mm.													
		Over 50		Up to 50 Over 120		Up to 120 Over 180		Up to 180 Over 260		Up to 260 Over 360		Up to 360 Over 500		Up to 500 Over 630	
From above	To	+	–	+	–	+	–	+	–	+	–	+	–	+	–
—	0.25	0.5	0.3	0.5	0.3	0.6	0.4	0.7	0.5	0.8	0.6	—	—	—	—
0.25	0.63	0.6	0.3	0.6	0.4	0.7	0.4	0.8	0.5	0.9	0.6	0.1	0.8	—	—
0.63	1.00	0.7	0.4	0.8	0.4	0.8	0.5	0.9	0.6	1.0	0.7	1.1	0.8	1.3	1.0
1.00	2.50	0.9	0.5	0.9	0.5	1.0	0.6	1.1	0.7	1.2	0.8	1.3	0.9	1.4	1.0
2.50	4.00	1.0	0.5	1.0	0.6	1.1	0.6	1.2	0.7	1.3	0.8	1.4	1.0	1.5	1.1
4.00	6.30	1.1	0.6	1.1	0.6	1.2	0.7	1.3	0.8	1.4	0.9	1.5	1.0	1.6	1.1
6.30	10.00	1.2	0.6	1.2	0.7	1.3	0.7	1.4	0.8	1.5	0.9	1.6	1.1	1.7	1.2
10.00	16.00	1.3	0.7	1.3	0.7	1.4	0.8	1.5	0.9	1.6	1.0	1.7	1.1	1.8	1.2
16.00	25.00	1.5	0.8	1.5	0.8	1.6	0.9	1.7	1.0	1.8	1.1	1.9	1.2	2.0	1.3
25.00	40.00	1.7	0.9	1.7	0.9	1.8	1.0	1.9	1.1	2.0	1.2	2.1	1.3	2.2	1.3

Table 13. Approximate Weight of Forgings, Prepared on Stamping Hammers and on Crank Hot-Stamping Presses, and Tentative Productivity of Hammers and Presses

Weight of incident parts of hammers in kilograms. Force of crank hot-stamping presses in m	Weight in kilogram.		Productivity in kg/hour.	
	from	to	of hammers	of pressers
630	–	2	200	400
1 000	1	3	300	600
1 600	2	6	500	1000
2 000	3	9	600	1200
2 500	4	13	750	1500
3 150	7	18	1000	2000
4 000	10	30	1250	2500
5 000	15	45	1600	3000
6 300	30	65	2000	4000
8 000	50	100	2500	5000
10 000	75	150	3200	6000

Table 14. Approximate Weight of Forgings, Prepared on Frictional Screw Presses, and Tentative Productivity of Presses [20]

Nominal force of press in m.	Weight in kilogram	Productivity in kg/hr.
100	До 0,2	60
160	0,2–0,5	80
250	0,5–2,0	200
400	2,0–5,0	400
630	5,0–8,0	560

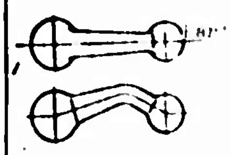
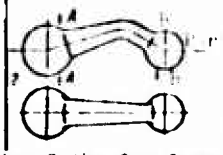
Disassembly for stamped parts, having unprocessed surfaces must be established on construction of a part, since on the selected disassembly depend the separate elements of shape of the part (presence or absence of drafts, possibility or impossibility of obtaining a given section of the part without machining and so forth). Requirements imposed on selection of disassembly (Table 15) should be considered also during construction of details processed around for the purpose of easing of subsequent composition of drawing of the forging.

Drafts. The lateral surface of a forging must be given an incline with respect to the direction of blow. This ensures the possibility of extracting the forging from the die. The incline of the inner walls should be made larger than that of the external walls. Vertical walls can be obtained only by subsequent treatment (cutting, pressing on stamping presses, drawing through a die and so forth).

By All-Union Government Standard 7505-55 are fixed the maximum permissible values of inclines of walls of the forging: for external up to 7° and internal, to 10° (Table 16).

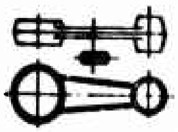
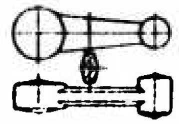
Table 15. Requirements Imposed on Selection of Surface of Disassembly [4], [7], [9], [18], [24]

1. To ensure possibility of extraction of forging from pass.

Correct	Incorrect
	

During disassembling 2 the for forging sticks in the lower half of the die in sections AA and BB and spherical heads are impossible to execute without distortion. During disassembly 1 the indicated deficiency is absent, but preliminary bending of the blank is necessary.

2. Disassembly is to be executed in such a way that the depth of cavities of the pass of the die are least, and the width of the biggest (filling of the form is facilitated, allowance with respect to draft are decreased, manufacture of the pass is simplified).

Correct	Incorrect
	

3. Disassembling is selected taking into account guarantee of simplicity of manufacture of forging and graphic dies, simplification of the stamping process, and reduction of expenditure of metal.

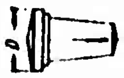
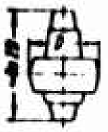
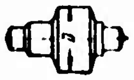
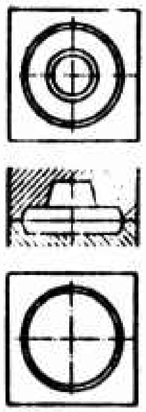
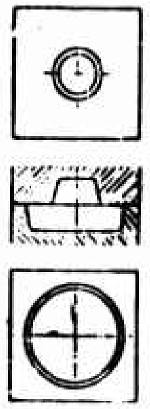
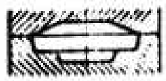
Correctly (simplification of tool and stamping, reduction of expenditure of metal).	Incorrectly (although satisfies p. 3)
	
Correct (Simplification of tool)	Incorrect (Although satisfies p. 3)
	

Table 15 (Continued)

4. Disassembly is to be done in such a manner that the contour of the cavity on the surface of disassembly in the upper and lower dies is identical (detection of shift of dies is facilitated). For nonfulfillment of this rule (for example, for the purpose of economy of metal etc.) in the die it is necessary to anticipate directrixes.

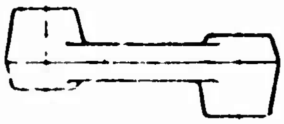
Correct	Incorrect
	

5. Disassembly is to be done in such a way that the parting line has adjoined to it vertical (with drafts) and not slanted walls (detection of shift of dies and cutting of burrs is facilitated).

Correct	Incorrect
	

6. Disassembling as far as possible is done on a plane, and not on a complex surface (preparation of dies is simplified).

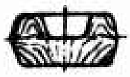
Desirable



Undesirable

Table 15 (Continued)

7. Selection of surface of disassembly must be done taking into account obtaining of proper macrostructure of forging, especially during stamping of nonferrous alloys

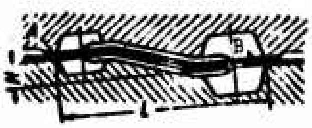
Correct	Incorrect
	

if the part operates on shift in plane A-A

A. The parting surface is desirably arranged in such a way that in case of appearance during stamping of shear forces the latter are balanced.

Points A and B on one level. Shear forces are balanced, but drafts are increased to the angle

$$\gamma = \operatorname{arctg} \frac{H}{L}$$



Points A and B are not on one level. Drafts are normal, but for balancing of shear forces in the die the directrix C is necessary.

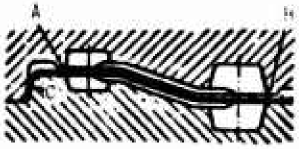
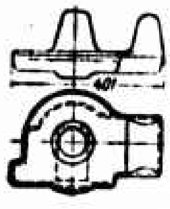
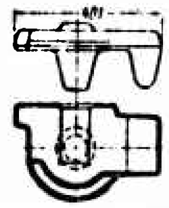


Table 15 (Continued)

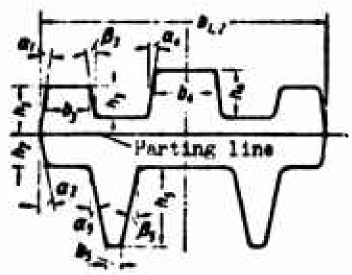
9. If forging is asymmetric about the parting surface, then during stamping on a hammer the higher and more narrow ribs, flanges, and bosses should be stamped in the upper half of the die.

Correct	Incorrect
	

10. During selection of the parting line one should consider the nature of production. In small-lot production it is possible to select the parting line keeping in mind maximum simplicity and least cost of the die, at least in damage to productivity of stamping. In big serial production, conversely, productivity has the biggest value.

Note: Indication 1 is obligatory in all cases. Remaining requirements (if it is impossible to execute them simultaneously) must be considered depending upon which of them under the given conditions are the most important.

Table 16. Drafts of Steel Forgings in Degrees



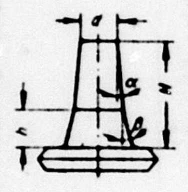
$\frac{h_n}{b_n}$ For n-th section of forging	Stamping on hammers and mechanical presses without ejector.		Stamping on mechanical presses with ejector.	
	α	β	α	β
To 1	3	5	1	2
1–2.5	5	7	2	3
Above 2.5	7	10	3	5

Note: For simplification of manufacture of the die it is desiralbe to designate drafts for all sections of forging by identical with respect to maximum $\frac{h_n}{b_n}$.

Drafts for parts made of nonferrous alloys (aluminum, magnesium) during stamping in dies without ejectors should be designated one degree less than for steel, that is 7° instead of 10°, 5° instead of 7°, etc, and for titanium alloys, one step higher.

During stamping of relatively high forgings both of steel and of nonferrous alloys, having the shape of a solid of revolution, it is possible to use also double drafts (Table 17).

Table 17. Double Drafts



Ratio $\frac{H}{d}$	Incline in degrees α	β
To 1.5	2	5
1.5—3	3	7
Above 3	5	10

$$h = \frac{H}{3}$$

<u>Radii of curvature</u>. All transitions from one surface of forging to other must be carried out chamfering (Table 18). Sufficient radii of curvature of the exterior angles should be designated also at junctures of surfaces of the part obtained after machining. In this case the optimum value of external radius of curvature for a part is determined by the relationship (Fig. 31a)

$$r_{\text{д}} \geqslant r_{\text{п}} - \Pi_{\text{н}},$$

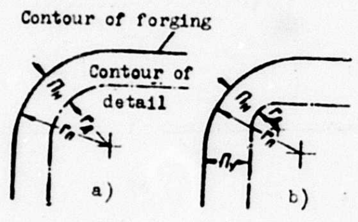
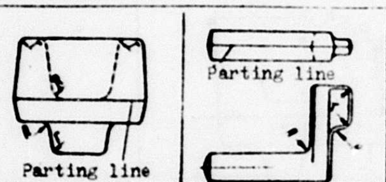


Fig. 31. Relationship between magnitudes of allowance and radius of curvature.

Table 18. Magnitude of Radii of Curvature for Steel Forgings (by All-Union Government Standard 7505-55)



Weight of forged piece in kg.	Radius of curvature of exterior angles r in mm for forgings of groups of accuracy: 1st	2 and 3rd
To 0.25	0.8	1.0
Above 0.25 до 0.63	1.0	1.5
" 0.63 " 1.60	1.5	2.0
" 1.60 " 2.50	1.5	2.5
" 2.50 " 4.00	2.0	3.0
" 4.00 " 6.30	2.5	3.0
" 6.30 " 10.00	2.5	3.5
" 10.00 " 16.00	2.5	3.5
" 16.00 " 25.00	3.0	4.0
" 25.00 " 40.00	3.0	4.0
" 40.00 " 63.00	3.0	4.5
" 63.00 " 100.00	3.5	4.5
" 100.00 " 125.00	3.5	5.0
" 125.00 " 160.00	4.0	6.0
" 160.00 " 200.00	5.5	8.0

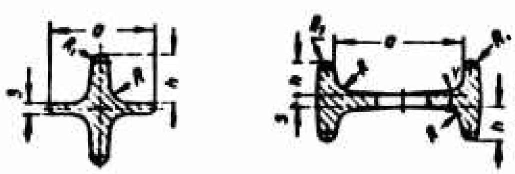
<u>Note</u>: Radii R of curvature of internal angles have to be larger than radii r of curvature of the exterior angles by 2-3 times.

where $r_{\text{Д}}$ is the radius of curvature of the exterior angle of the part; $r_{\text{П}}$ is

the same, necessary in forging; Π_H is the magnitude of the normal allowance. Disturbance of the indicated relationship requires increased allowance Π_y with respect to the walls if we preserve normal allowance Π_H with respect to the angle (Fig. 31b).

Recommended radii of curvature and also minimum thickness of blade for forgings from nonferrous alloys are shown in Tables 19-20a.

Table 19. Thickness of Blade of Forgings from Aluminum, Magnesium (MA2 and V95) and Titanium Alloys (Cross Sections Open and Closed) [38], [39]



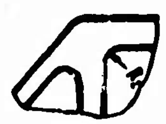
Area of projection of forging on the parting plane in cm^2	Aluminum and magnesium alloys, s for distance between ribs a in mm: До 60	60–100	100–160	160–250	250–400	Titanium alloys s in mm
To 100	1.5	2.0	–	–	–	–
100–160	2.0	2.5	3.0	–	–	3.5
160–250	2.5	3.0	3.5	–	–	4.5
250–400	3.0	3.5	4.0	4.5	–	5.0
400–630	3.5	4.0	4.5	5.0	6	5.5
630–1 000	4.0	4.5	5.0	6.0	7.0	7.0
1 000–1 600	4.5	5.0	6.0	7.0	8.0	9.0
1 600–2 500	5.0	6.0	7.0	8.0	9.0	11.0
2 500–4 000	6.0	7.0	8.0	9.0	10.0	–
4 000–6 300	7.0	8.0	9.0	10.0	11.0	–
6 300–10 000	8.0	9.0	10.0	11.0	12.0	–

Note: In the absence of facilitating apertures, values of s are taken as for the following interval of areas of projections, i.e., a row lower.

Table 20. Radii of Curvature R and R_1 in mm of Forgings from Aluminum and Titanium Alloys (Closed Cross Sections, see Fig. to Table 19) [38], [39]

Height of rib h in mm.	Distance between ribs a in mm. Over 40: Aluminum alloys R	Aluminum alloys R_1	Titanium alloys R	Titanium alloys R_1	40–80: Aluminum alloys R	Aluminum alloys R_1	Titanium alloys R	Titanium alloys R_1	80–125: Aluminum alloys R	Aluminum alloys R_1	Titanium alloys R	Titanium alloys R_1
Over 5	4	1.5	3	1.5	8	1.5	5	1.5	10	2	10	2
5–10	5	1.5	4	1.5	8	2.0	8	2.0	12.5	2	12.5	2
10–16	6	2	6	2	10	2.5	10	2.5	12.5	2.5	15	2.5
16–25	8	2.5	10	2.5	12.5	3.0	12.5	3	15	3	15	3
25–35	10	3	–	–	15	3.5	15	3	15	3.5	15	4
35–50	12	4	–	–	15	4	15	4	15	4	20	5

Table 20a. Radii of Curvature R, R_1 and R_2 in mm of Forgings from Aluminum, Magnesium and Titanium Alloys (Open Sections, see Fig. to Table 19) [31], [38], [39]



Height of rib in mm.	R_1			R	R_2
	Magnesium alloys		Aluminum and titanium alloys	Aluminum, titanium and magnesium alloys	
	MA3	MA5			
Up to 5	2.0	3.5	1.0	2.5	3
Over 5 • 10	2.0	3.5	1.5	4.0	5
• 10 • 15	2.0	3.5	2.0	5.0	6
• 15 • 20	2.0	3.5	2.0	6	10
• 20 • 25	2.5	3.5	2.5	8	12.5
• 25 • 35	3.0	3.5	3.0	10	12.5
• 35 • 50	4.0	4.0	4.0	12.5	15
• 50 • 60	5.0	5.0	5.0	15	20
• 60 • 70	6.0	6.0	6.0	15	20

Technology of stamped forgings.

For the purpose of simplification of the technological process and increase of durability of dies during construction of stamped details one should follow the indications of Table 21.

Weight and dimensions of blank. The weight of the initial material $G_{ис}$ is approximately determined by the formula

$$G_{ис} = G_{пк} + G_{з} + G_{уг},$$

where $G_{пк}$ is the weight of the forging; $G_{з}$ is the weight of waste in burrs and $G_{уг}$ is the weight of waste during heating.

Table 21. Construction Indices of Parts, Stamped in Open Dies [6], [7], [8], [9], [18], [32], [35], [37]

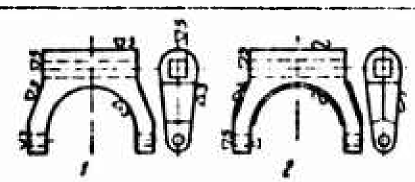
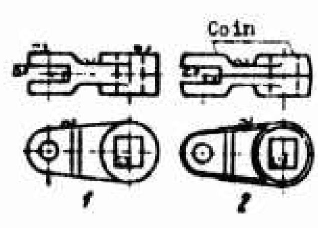
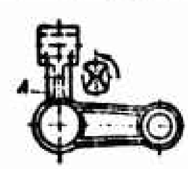
1. Surfaces of detail, not touching with surfaces of other details, as a rule, left untreated and replacing treatment as far as possible by cutting by sizing (stamping):	
a) Treatment of surfaces of detail 1 to ∇ of excess – these surfaces are non-working. The detail may be designed in form 2 with assignment of drafts and assignment of treatment of only holes and butt surfaces.	
b) For detail 1 is foreseen treatment ∇3 of the butts of the losses and external surfaces of the fork at the same time as necessary accuracy and cleanness of surface may be obtained by planar sizing. The lateral surface is shown unprocessed, however, it is impossible to execute this surface by stamping as a result of absence of drafts. Correct construction is represented by part 2.	
c) Designing this or another surface of the detail of untreated, it is necessary to check the possibility of disassembly of dies. Stem A of the lever cannot be carried out in forging as double-T. Stamping is possible, if stem A is rotated by 90 degrees (by a pointer) or it is executed as oval.	

Table 21 (Continued)

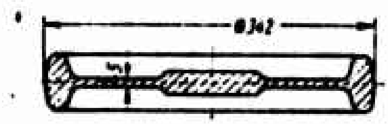
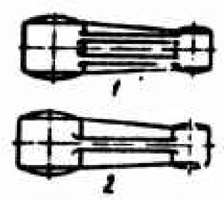
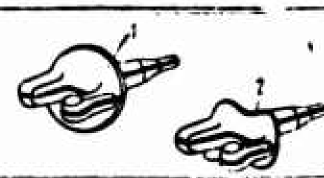
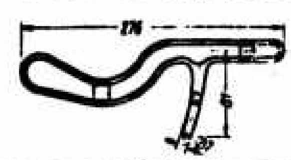
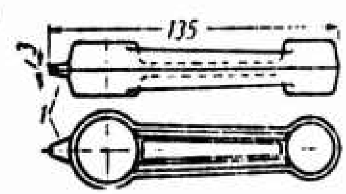
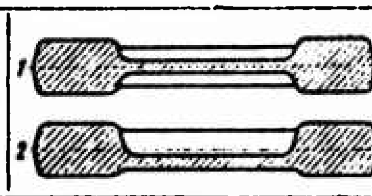
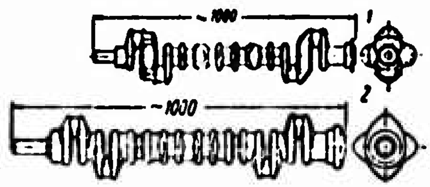
2. To aspire to possibly smaller difference in areas of cross sections of details in different sections of its length; to avoid thin walls, high ribs, especially closely located one to other, flanges, protrusions, bosses, long branches and thin influxes, adjoining to the parting plane (decrease of labor-consumingness, lowering of rejects and expenditure of metal):	
a) Sharp difference in sections and small thickness of flange hamper stamping and cause increased rejects with respect to clamps and incompleteness of figure.	
b) A thin disk determines low durability of the die due to fast cooling and high resistance of deformation. Repeated heatings are required for combatting inadequate stamping; rejects increased	
c) For detail 1 two parallel high ribs are located impermissibly closely one to other. Flow of metal is hampered, rejects increased (unfilled, clamps), durability of die low. Correct construction of detail 2 is correct.	
d) For detail by sketch 1 a thin flange of large diameter hampers stamping; change of construction by sketch 2 ensures lowering of labor-consumingness by 1.5 times.	
e) Long thin branch conditions great waste of metal during stamping (75% of weight of forging) and increased rejects because of unfilled figure.	
f) Thin influx 1, adjoining to parting plane is subjected to breaking, breakdown, cleaving on cold cutting of burr and sticking in the die during hot cutting.	
3. To aspire to symmetric form of detail with respect to parting plane and to symmetric inclines of protruding walls (simplification of manufacture of dies, easing of process of stamping, lowering of rejects for misalignment):	
a) Configuration 1 is desirable: cavity of upper and lower stamps are identical, in the process of stamping a forging it is possible to turn for blow out of a cinder and best shaping of figure. Configuration 2 does not allow this and is undesirable.	 Parting plane
b) Detail 1 has a wall with unequal slope to the parting plane, in consequence of which during stamping forces arise striving to shift one half of the stamp relative to the other. Detail 2 does not have this deficiency.	

Table 21 (Continued)

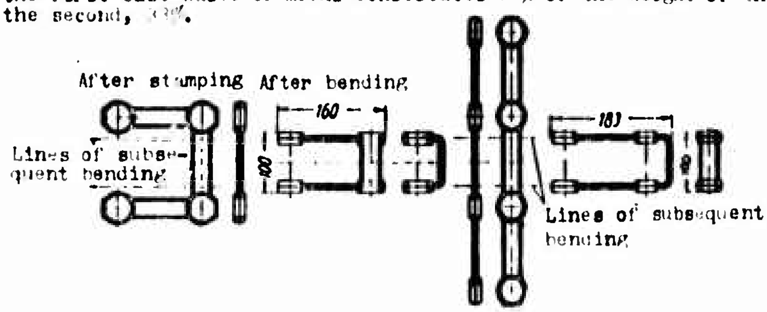
4. An effort is made to give a part this configuration in order that during preparation of a forging additional twisting or bending operation are not required, and the number of basic operations is cut (lowering of labor consumption).

a) An eight-throw crankshaft 1 cannot be stamped with location of elbows at a 90 degree angle due to failure in configuration of cheeks, not giving possibility of establishing parting. Elbows are stamped in one plane and then by an additional operation they are molded on a special machine. An eight-throw shaft 2 thanks to identical elliptic form of cheeks allows disassembling of dies and may be stamped immediately with elbows, located at an angle of 90 degrees without molding.

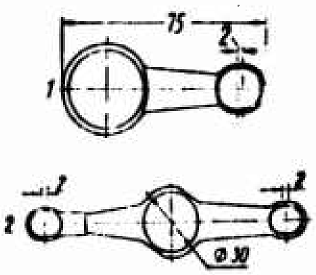


b) The shackle depicted on the left is stamped in reamed form after which it is bent. The shackle depicted on the right also is stamped in reamed form, but during stamping does not require a bending pass; therefore the forging has a simple shape.

In the first case waste of metal constitutes 87% of the weight of the forging in the second, [illegible].



5. With the necessity after drilling of holes of exactly guaranteeing a minimum thickness of walls in the heads of levers, connecting rods and so forth for two heads one oval 1 is made, and for three-two extreme 2.



6. To check in every separate case the expediency of manufacture of a detail from two or several parts with subsequent welding and, conversely, the possibility of unification in one forging of adjacent details, fastened by one or another method:

a) Manufacture of connecting rod of welded construction from two stamped elements 1 and 2 allows significant lowering of labor-consumingness and expenditure of metal, and also use of equipment of smaller capacity.

b) During stamping of a core fork with a long rod a number of problems arise – difficulty of executing a clean cut, oval shape of rod; waste constitutes over 90% of the weight of the forging. For welded construction (element 1 is made by stamping, but element 2 – from a tube) the indicated deficiencies are removed, waste is lowered approximately two times.

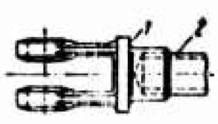


Table 21 (Continued)

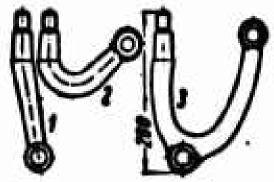
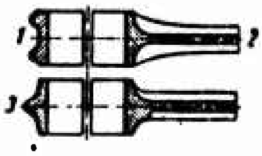
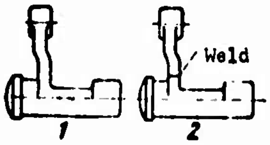
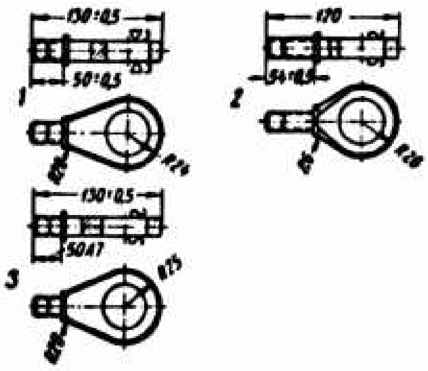
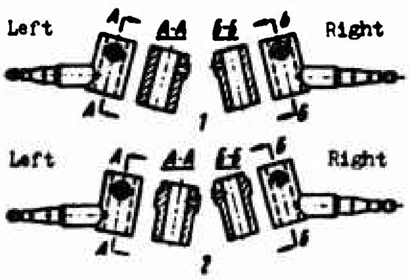
c) Levers 1 and 2 secured in a third detail can be designed as one detail 3. In spite of a more complicated process of stamping of the latter, this variant is more profitable due to saving of about 1 kg of metal.	
d) Unsuccessful construction of cover 1 with two ribs does not allow stamping it in one forging with connecting rod 2. Waste of metal only on forging of the connecting rod constitutes 65% of its weight. Construction 3 gives the possibility of uniting forging of the connecting rod and cover. The necessity drops for a separate die for the cover; labor-consumingness is lowered, waste during stamping is reduced approximately to 40% of the weight of the forging.	
e) Stamping of the lever in one forging 1 turned out to be more economical than manufacture of it from two parts 2 with welding.	
7. It is necessary to aspire to unification of analogous details for the purpose of obtaining of them from identical forgings:	
a) Insignificant changes in constructions of details 1 and 2 allow replacement of them by one detail 3. The number of dies is reduced, seriality is increased.	
b) Replacement of bosses by a belt in the right and left details 1, or introduction of two bosses in place of one allows execution of them from identical forgings 2.	

Table 21 (Continued)

8. For one-sided relative to the parting plane location of ribs, flanges and other difficult-to-fill sections of a forging, stamped in the upper part of the die, it is necessary to anticipate signs in the form of flanges or cavities, ensuring correct position of the stamped forging in the lower part of the die for repeated blows of the hammer.	

9. Ribs of variable height should be executed with identical width of peak with respect to the entire length of rib and a constant draft:

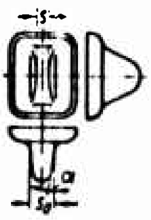
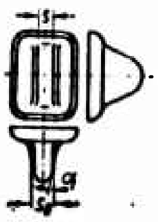
		
a) Width of peak s and angle a are constant, width of base s_0 variable – is recommended.	b) Width of base of rib s_0 and angle a are constant, width of peak s variable – permissible.	c) Width of peak s and base s_0 of rib are constant, angle a variable – undesirable.

Table 22. Passes of Hammer Dies

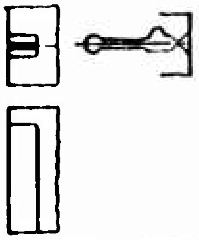
Designation of Passes	Use
Stamping:	
Final (finishing)	Obtaining of forgings in final form and dimensions by drawing;
preliminary (rough);	Attaching to forging of form, close to ready, for increase of durability of final pass;
Stockpiling:	
forming; 	Attaching to blank of form corresponding to contour of forging in the parting plane;

Table 22 (Continued)

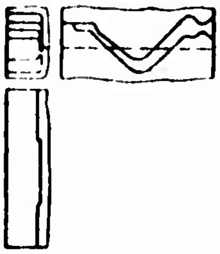
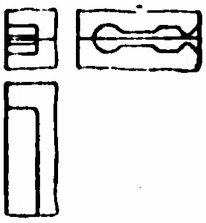
Designation of Passes	Use
Bending 	Bend of blank before stamping of forging with a bent axis;
squeeze; 	Insignificant shift of metal of initial blank along the axis with a decrease of areas of its cross sections in some sections and an increase in others; .

Table 22 (Continued)

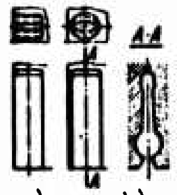
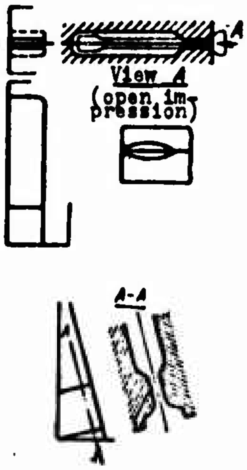
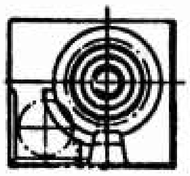
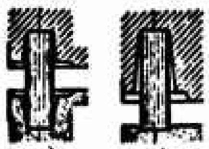
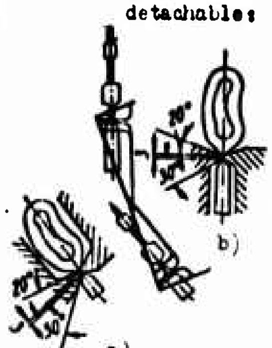
Designation of Pass	Use
rolled  a) b) a - open, b - closed	Distribution of the volume of material along the axis of the blank in accord with distribution of it in forging
drawing 	Reduction in area of cross section in separate sections of initial blank with simultaneous increase in their length
upset 	Increase in cross section of the initial blank at the expense of decrease of height
upsetting  a) b)	Upsetting of a section of the blank a - in middle part, b - on the butt

Table 22 (Continued)

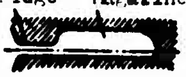
Designation of Pass	Use
detachable:  a) b) a - front, b - real	Cut from the rod of the ready forging, when from one blank more than two forgings are stamped

The weight of waste in burrs tentatively can be found from the expression

$$G_з = (0{,}5 + 0{,}8)\,\gamma S f_з,$$

where γ is the specific gravity of the metal; S is the perimeter of the forging along the parting line; $f_з$ is the area of the section of the groove for burrs (Table 23). Large values of the coefficient are selected for forgings of complicated configuration.

Table 23. Approximate Values of Ares of Cross Section of a Groove for a Burr Depending Upon the Weight of the Forging [7]



Weight of forging in kg	To 0.2	0.2–0.5	0.5–2.0	2–5	5–25	25–100
Area of cross section of groove in cm^2	0.2–0.5	0.7–0.9	1.2–1.4	1.7–2.4	3.2–4.2	5.3–11.3

Waste $G_{\text{уг}}$ during heating in ordinary reverberatory furnaces may be assumed equal to 1.5-2.5% of the weight of a forging with a burr ($G_{\text{пк}}$ + $G_{\text{з}}$); during non-scale heating in furnaces or during electrical heating (induction or contact), 0.5%.

Expenditure of metal on forging will be larger than that obtained by the given formula for the weight of initial material $G_{\text{нс}}$, since in it we do not consider the loss on fins and back of multiplicity during cutting of blanks.

Dimensions of blank. a) For forgings round and square in design or close to such form, stamped with installation of a round or square blank in a die impression on the butt, the area of cross section and length of blank are determined just as during free forging by upsetting (see P. 101).

b) For forgings of elongated form (stamped with stacking of initial blank in a die impression "block") with small difference of cross sectional area in different sections of length, during stamping of which on a hammer the use of drawing is not required and during stamping on a press and for rolled stock, the area of cross section of the blank is determined by the formula

$$F'_{\text{нс}} = \frac{(1{,}02 \div 1{,}30)\, V_{\text{нс}}}{L_{\text{пк}}},$$

where $V_{\text{нс}}$ is the volume of the blank; $L_{\text{пк}}$ is the length of the forging.

The formula is real, if the value obtained by it for hammers

$$F'_{\text{нс}} \geqslant (0{,}5 \div 0{,}7)\, F_{max};$$

for presses

$$F'_{\text{нс}} \geqslant 0{,}7\, F_{max},$$

here F_{max} is the area of maximum cross section of forging with addition of the area of a burr from two sides equal to $2(0.5\text{-}0.8)f_{3}$, where f_{3}

is the area of cross section of groove for the burr (Table 23).

For forgings, the areas of cross section of which in different sections of length are distinguished significantly one from another, a blank during stamping on hammers is subject to local drawing. The area of cross section of it in this case tentatively one can determine by the formula

$$F''_{ne} = (0{,}7 + 1)\,F_{max}.$$

For stamping on presses the initial blank for such forgings must be prepared on another machine or periodic rolled products used.

Stamping on hammers is the most wide-spread. One of its advantages is the possibility of doing on one hammer in a multipass die (Table 22) all necessary preparatory and purely stamping operations, using as initial material rod rolled products. However the productivity of stamping on hammers significantly is increased, and expenditure of metal is reduced during realization of preparatory operation partially or fully on other machines.

Selection of passes and their different combinations is done during development of the technological process of stamping depending upon the configuration and dimensions of forging, and also on requirements for direction of fiber. Forgings with small difference of areas of cross sections along the axis may be executed with application of forming or squeezing passes and also bending. For forging with large difference in areas of cross sections a roll pass is necessary. At last, for obtaining of forgings with a very great difference in areas of cross sections the necessity arises of a drawing stream. In a number of cases it is possible to avoid use of a rolled and drawing pass, stamping simultaneously two forgings, located next to each other in such a manner that the total areas of cross sections of forgings differ little one from another.

As an example in Fig. 32 a multipass die is depicted. The initial blank after heating proceeds for drawing of the end in a drawing pass 1, then into a closed rolled pass 2 for a set of material mainly in the middle part, further it is transmitted in a bending pass 3, after which the blank is stamped in a preliminary pass 4, final 5, and, at last, the ready forging is chopped from the rod in a rear detachable pass 6.

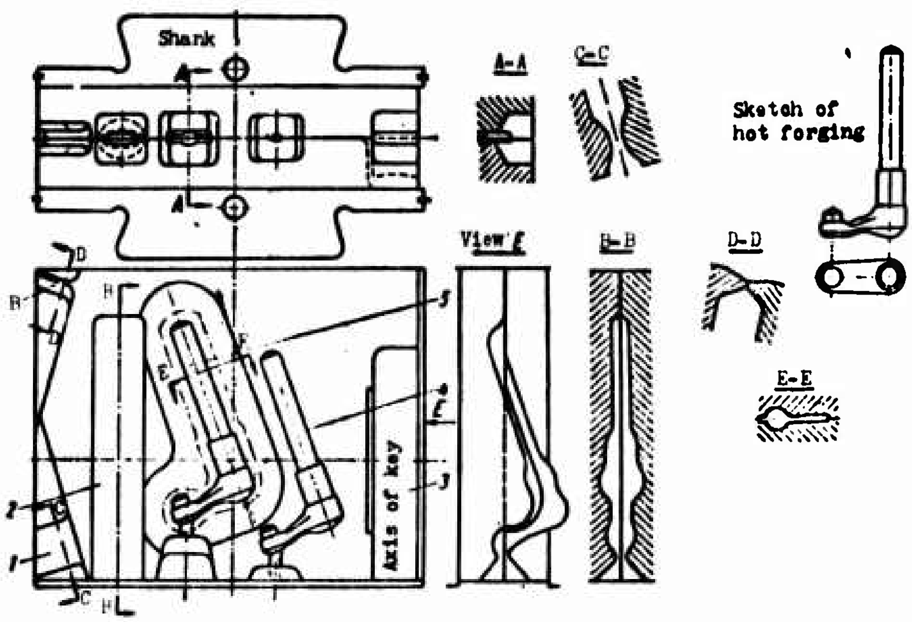


Fig. 32. Multipass hammer die.

Bracing of hammer dies is carried out with the help of swallow tails, inserted in corresponding nests of the ram of the hammer (upper part of the die) and sub stamp pad on the anvil block (lower part of the die) and secured by a wedge and key.

Material of hammer dies. The material for multipass dies is chiefly alloy stamping steel (see Vol. 6, Chapter IV). For dies, not requiring high durability perhaps carbon steel U7 is used. For the purpose of economy of alloy stamping steel, stamping passes frequently are executed in the form of inserts. In this case the stamping block (small cube) may be made of steel 40Kh or even of steel 45.

Stamping on crank presses. Crank presses for drop forging differ in rigidity of construction, intensive directrixes for accuracy of movement of the slider and the presence of a lower and upper ejector in the table and slider.

Stamping in open stamps on crank presses has a series of advantages over stamping on hammers. Among these are the following: increased accuracy of stamping; possibility of application of decreased drafts; smaller allowance on processing (All-Union Government Standard 7505-55) and also the possibility in a number of cases of doing without allowances, for instance, stamping of a gear with teeth; high productivity, exceeding the productivity of a hammer by 1.5-3 times, since every transition is carried out for one movement of the press; the possibility of mechanization and even automation of the supply of blanks to a die; great safety in operation.

During stamping on presses it is necessary:

a) to apply methods of heating, ensuring absence of noticeable cinder; for impossibility to carry out non-scale heating it is necessary to clean cinders from heated blanks before stamping;

b) not to use rolled and drawn finishing passes (it is expedient to use them only in small-lot production; see [3]). To avoid necessity of these passes during stamping of forgings with sharp difference of areas of cross sections along the axis sometimes is possible by means of doubling of the forged pieces (Fig. 33), and also by transition to stamping obtaining thin rod-like segments by means of extrusion (Fig. 34).

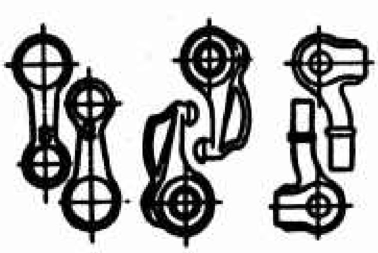


Fig. 33. Examples of doubled location of forgings for stamping.

In these cases when doubling of the forged piece does not do away with the necessity of rolling or drawing, the forgings must be faced in

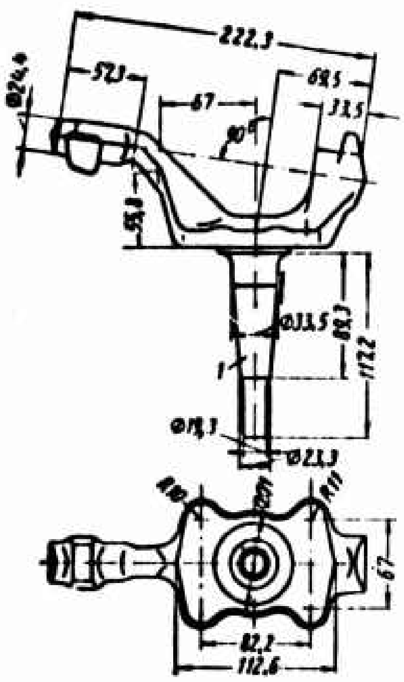


Fig. 34. Forging with rod 1, obtained by pressing.

advance on another machine or rolled products of periodic profile used.

For the purpose of easier filling of the form of the final pass in all cases it is recommended to dismember the process into a number of transitions, even during stamping of forgings of relatively simple form (Fig. 35).

Passes of dies of crank presses are constructed usually in the form of prismatic or cylindrical inserts, secured in plate-casings by bolts with the help of support planks or tack welds (Fig. 36). For guarantee of maximum accuracy of mutual direction of upper and lower dies directrixes of the column (Fig. 36) are used. For easing of recession of a forging the bottom of the deepest part of the cavity of the pass in the inserts is executed as a separate part – ejector (Fig. 37).

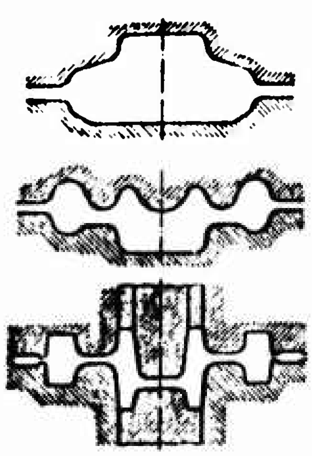


Fig. 35. Example of consecutive transitions during stamping on a crank press.

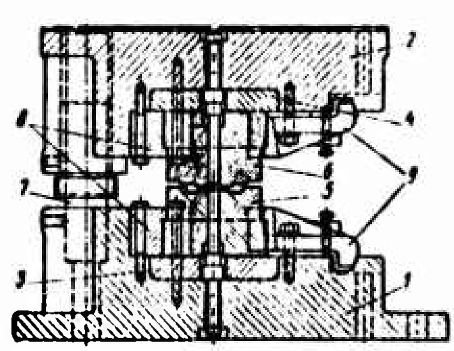


Fig. 36. Dies of a crank press with directing columns: 1 and 2 – lower and upper plates; 3 and 4 – lower and upper underlaid plates; 5 and 6 – lower and upper pass inserts; 7 – directing columns; 8 – support planks; 9 – tack welds.

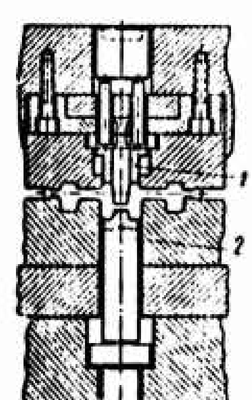


Fig. 37. Ejectors in the die of a crank press; 1 – annular; 2 – rod.

In avoidance of operation of press during stamping closing of pass inserts is not allowed for the extreme low position of the slider.

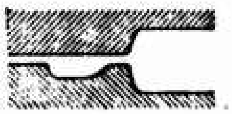


Fig. 38. Groove for the burr of the die of a crank hot-stamping press.

Therefore the groove for the burr in dies of the crank hot-stamping presses has a form (Fig. 38), somewhat different from that for hammer presses.

Stamping on frictional screw and hydraulic presses. Stamping in open dies of steel and non-ferrous alloys on frictional presses is used preferably in small-lot production for obtaining of forgings of small weight, as a rule, in a monopass die. Stockpiling operations of rolling and drawing are not executed.

Along with forgings (Fig. 30), mainly with small difference of areas of cross sections by length, on frictional presses it is possible to stamp by upsetting of forgings, having the form of a rod with head (bolts, rivets, and so forth).

The possibility of stamping by upsetting is conditioned by the presence for frictional presses of a lower ejector that also allows use of decreased drafts.

Dies of frictional screw presses must be made with directrixes.

On hydraulic presses in open stamps chiefly big forgings of steel and aluminum alloys are made and also forgings of various dimensions from magnesium alloys, where for small and average forgings multipiece stamping is used. Special attention during stamping on hydraulic presses should be given purification of heated blanks before putting in the die. On hydraulic, just as on other presses, it is possible to use ejectors.

The dimensions of forgings stamped on a press with a given force may be increased by means of application of sectional stamping [24].

Stamping in Closed Dies

For stamping in closed dies metal is deformed in a closed cavity (Fig. 39). An insignificant burr can be formed only in the final period of stamping from flowing of metal into a gap A between the lateral walls of the upper and lower part of the die.

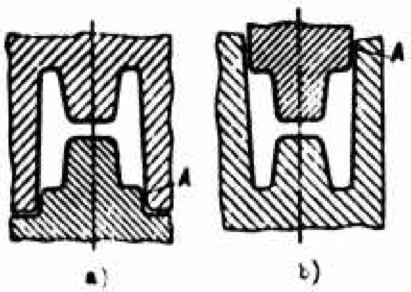


Fig. 39. Diagram of closed die: a) for hammer; b) for press.

During stamping in closed dies on hammers, a parting line and drafts are desirably disposed as is represented in Fig. 39a, and during stamping on presses, according to Fig. 39b. Shapes of forgings stamped in closed dies are significantly less various and are more simple (Fig. 40) as compared to forgings, obtained in open dies.

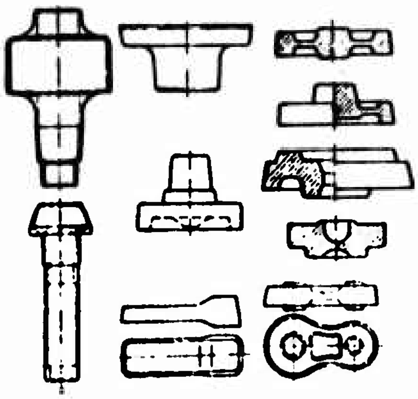


Fig. 40. Examples of certain forms of forgings, stamped in closed dies.

Furthermore, it is impossible to stamp forgings, the vertical sections of which determine the presence of sharp edges in the punch.

A basic advantage of stamping in closed dies is reduction of expenditure of metal in connection with absence of an annular burr, and also a more favorable diagram of state of strain that is specially important for stamping of small-plastic alloys. During stamping in closed dies it is necessary to ensure the most exact possible weight of the blank, and also cleanness and parallelism of its butts, to use non-scale methods of heating or to clean the heated blank well of cinder.

Oscillations in the volume of the initial blank during stamping in closed dies on hammers, frictional and hydraulic presses increase

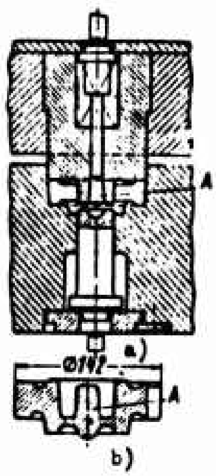


Fig. 41. Closed die with magazine: a) die; b) forging.

the field of allowance with respect to height. In dies of crank hot-stamping presses it is necessary to anticipate magazine A (compensator) for compensation of volume variations of the blank (Fig. 41).

For stamping in a closed die for preparation of the blank it is possible to use stockpiling and preliminary passes. The latter, in turn, can be open or closed. Angles of inclination of walls and radii of curvature are in Tables 16-21.

Stamping in closed dies by pressing and piercing [27], [31]. Stamping by extrusion (Fig. 42) for types of forgings, represented in Fig. 43a, ensures greater approximation of shape of the forging to the shape of the ready detail and increases productivity. By the process of extrusion both stamping on hammers and presses in open dies may be replaced (for instance, the rotating cam in Fig. 44, fork), and stamping on a horizontal-forging machine (for instance, valve, bushing with flange) with obtaining of rod sections both solid and hollow. Final shaping of heads sometimes is done in a closed or open pass for an already extruded rod part.

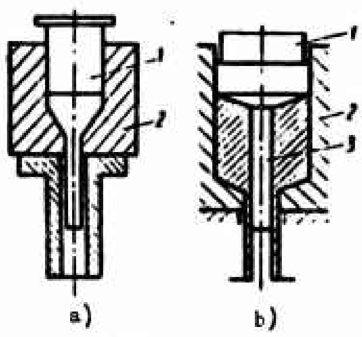


Fig. 42. Diagram of stamping by extrusion: a) of solids; b) of hollow rod forgings. 1 – punch; 2 – die; 3 – mandrel.

Obligatory for stamping by pressing is the presence in the press of an ejector. It is most expedient to use a crank hot-stamping press of special construction.

Stamping by piercing in a closed nondetachable die is used for obtaining of hollow forgings (Figs. 43b and 45).

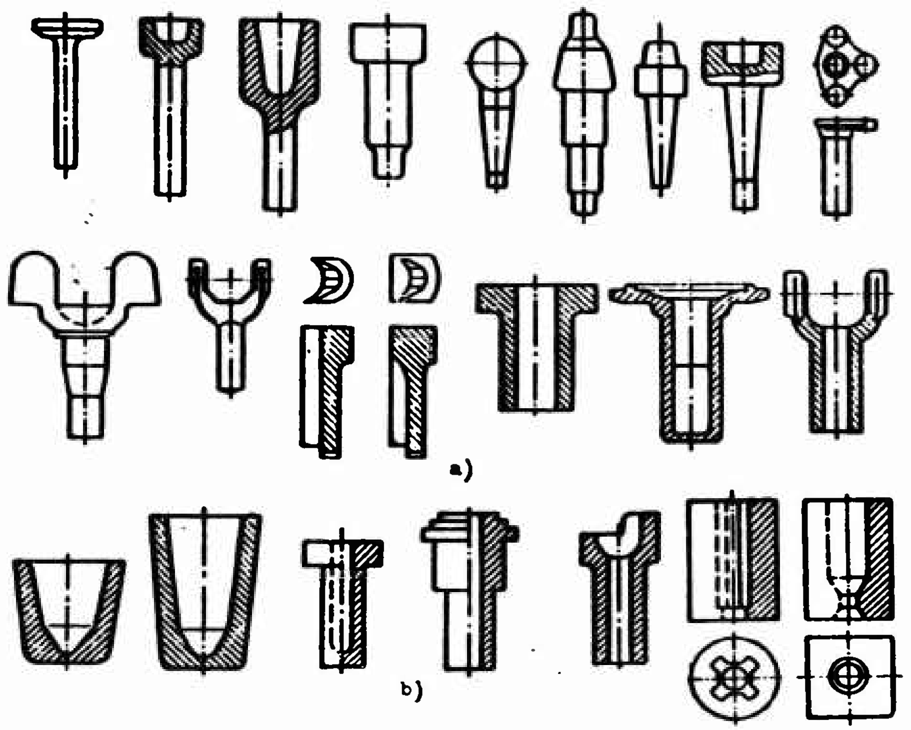


Fig. 43. Examples of certain forms of forgings, stamped by pressing (a) and punching (b).

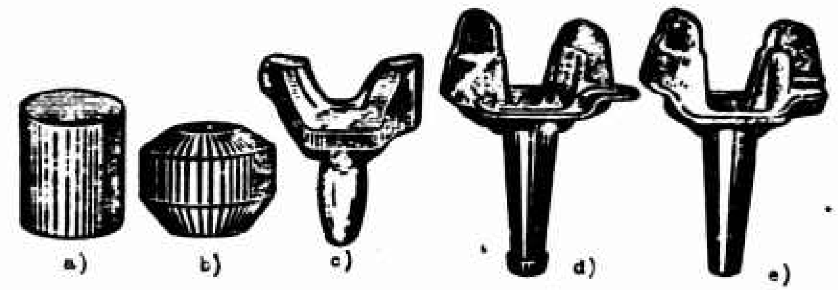


Fig. 44. Transitions of manufacture of forging of the rotating cam by combined extrusion [20]: a) blank; b) upsetting and beginning of obtaining of shank pressing by extrusion; c) stamping in a preliminary pass; d) final stamping; e) cutting of the burr (on a cutting press).

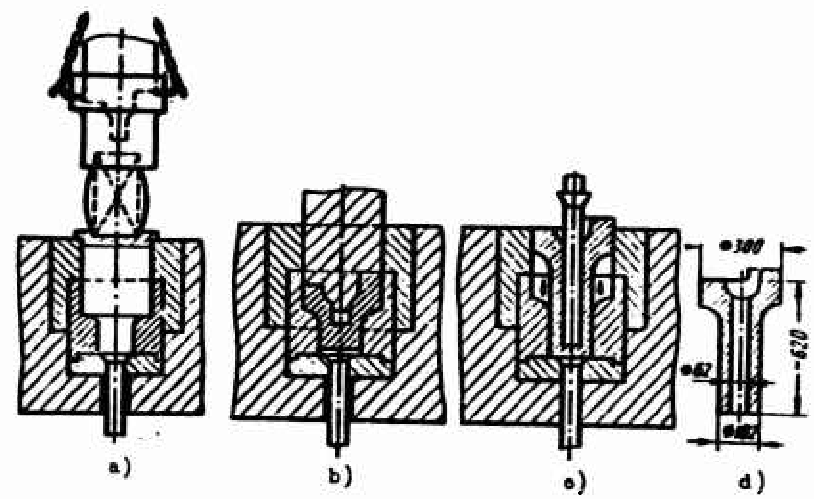


Fig. 45. Diagram of stamping by piercing of bushing weighing 50 kg with a shaped head [31]: a) upsetting of the blank; b) stamping with preliminary piercing; c) final piercing; d) ready forging.

Stamping in Dies with Split Matrices

Depending on the shape of the forging the parting line of the die is made vertical (Fig. 46) or horizontal (Fig. 47). Besides the parting line of the matrices insertable punches are used, removed from the forging after extraction of it from the die.

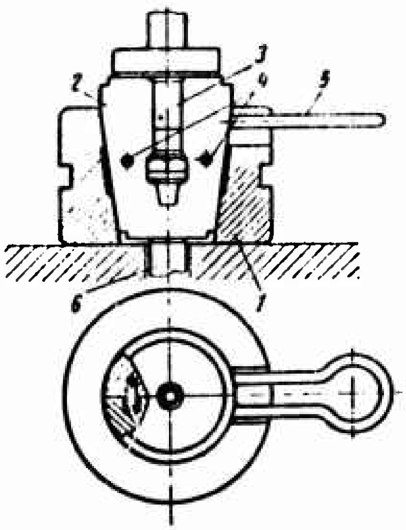


Fig. 46. A closed die with split matrix for stamping on a screw friction press: 1 – casing; 2 – split die; 3 – punch; 4 – fixatives; 5 – handle; 6 – ejector.

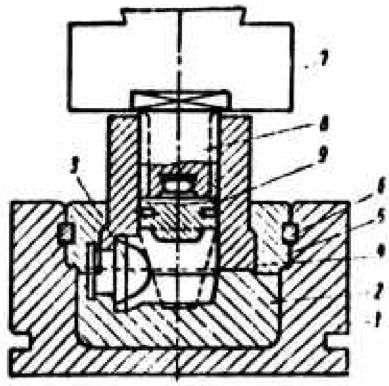


Fig. 47. Closed die with split matrix for stamping on a hydraulic press: 1 – body; 2 – lower matrix; 3 – lateral punches; 4 – upper matrix; 5 – clamp plate; 6 – wedges; 7 – shank; 8 – holder; 9 – punch.

Stamping on presses in dies with a split matrix allows obtaining of a forging (Fig. 48) without a burr, decrease in allowances (Fig. 49 and 50) and a number of transitions, up to stamping in one transition.

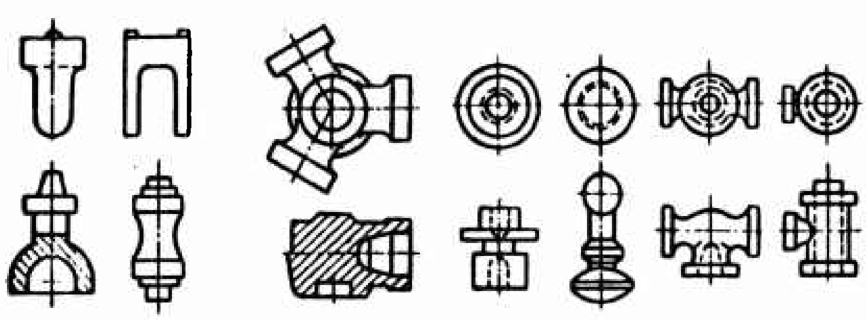


Fig. 48. Examples of forms of forgings, stamped in closed dies with a split matrix.

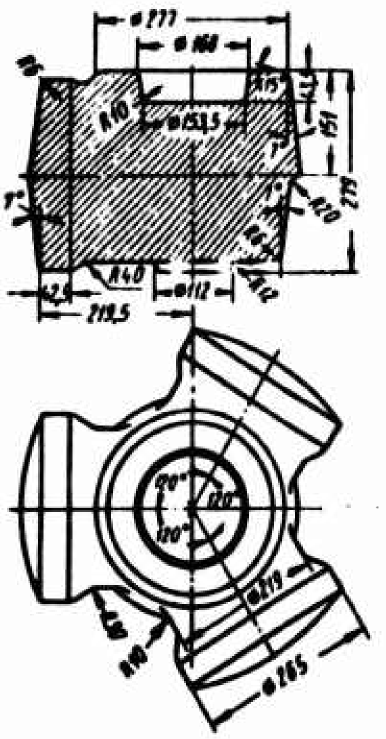


Fig. 49. Forging of a bushing, stamped on a hammer (weight of forging 216 kg).

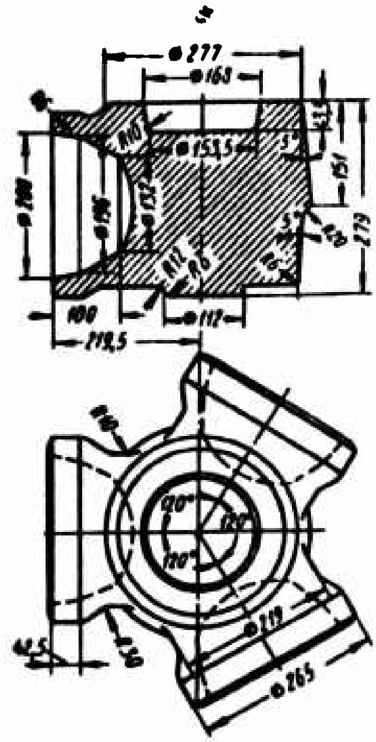


Fig. 50. Forging of a bushing, stamped on a press (weight of forging 153 kg).

For stamping in closed dies with a split matrix in big-serial and mass production it is necessary to use attachments, automating clamping and disassembling of the matrices. Still more suitable are special machines (presses with several sliders, press of double action and others). Special presses give the possibility of not only disassembling the die, but use of additional mobile punches (Fig. 51).

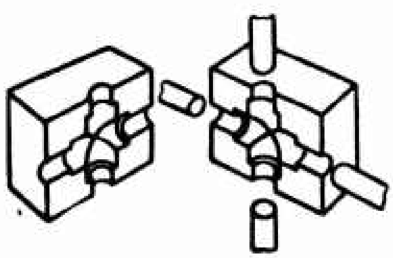


Fig. 51. Diagram of die with additional punches.

Stamping on horizontal-forging machines. The most characteristic for stamping on horizontal-forging machines are the operations of upsetting and piercing. However on these machines it is possible to carry out also other operations, somehow: bending, squeezing, cutting of the rod, etc.

Among the advantages of stamping on horizontal-forging machines are high productivity, the possibility of stamping without a burr or with a very insignificant burr, the possibility of obtaining a forging of the ring type without waste on core punch, with good macrostructure etc. Nonetheless, with a horizontal-forging machine it is impossible to replace a stamping hammer or hot-stamping press, inasmuch as it is applicable for manufacture of forgings of details of definite types (Fig. 52). In separate cases it is possible with benefit to replace stamping on a horizontal-forging machine by stamping by extrusion.

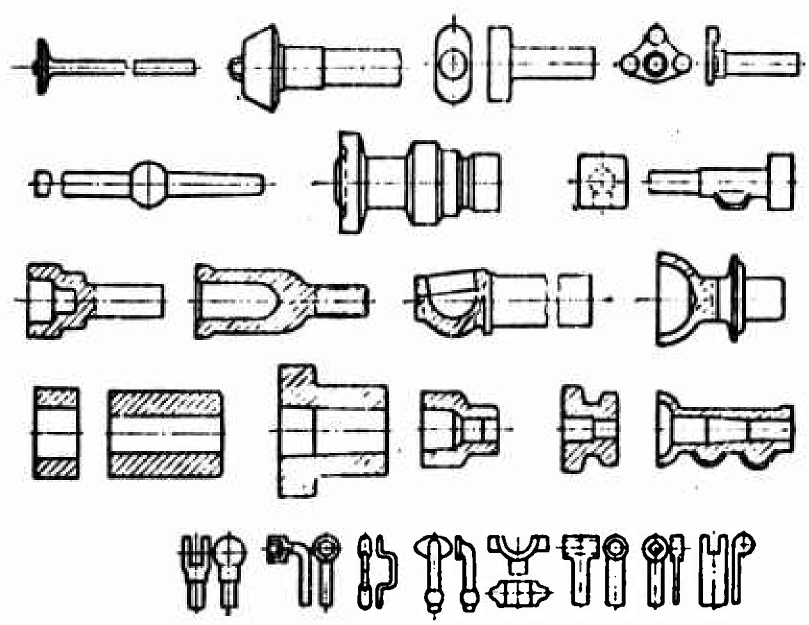


Fig. 52. Examples of forgings, stamped on horizontal-forging machines.

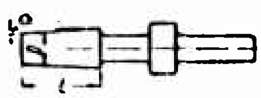
Approximate data about productivity of horizontal-forging machines, and also about dimensions of initial material and forgings obtained are given in Table 24. Certain indications, concerning construction of the forgings, are given in Table 25.

Table 24. Approximate Data About Productivity of Horizontal-Forging Machines and Dimensions of Initial Material and Forgings [5], [20]

Parameters	Nominal force of machine in m											
	100	160	250	400	630	800	1000	1250	1600	2000	2500	3150
Hour productivity in kilograms.	50	100	200	300	500	600	700	800	900	1000	1100	1200
The biggest diameter of processed rod in mm. . .	20	40	60	80	100	120	140	160	180	210	240	270
The biggest diameter of forging in mm	40	55	70	100	135	155	175	195	225	255	275	315

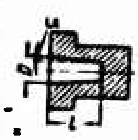
Table 25. Indications Concerning Construction of Details, Stamped on Horizontal-Forging Machines [4], [8], [9], [31], [32, [35]

1. It is necessary to assign drafts:
   a) On cylindrical sections of forging by length greater than 0.3 of their diameter, upset in the punch cavity — from $\alpha = 0.25$ at $L/D = 0.3$-1.3 to $\alpha = 1^\circ$ at $L/D = 3.3$-4.3.



   b) On beads, molded in deep circular cavities of matrices, — from $\alpha = 1^\circ$ at Λ up to 10 mm. to $\alpha = 10^\circ$ at Λ more than 80 mm.

   c) At the walls of deep apertures pierced by a punch, — from $\alpha = 0.25^\circ$ at $L/D = 0.5$-1.5 to $\alpha = 2^\circ$ at $L/D = 7.5$-8.5.



2. Transitions should be executed at radii not less than 1.5-2 mm.

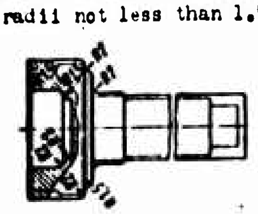
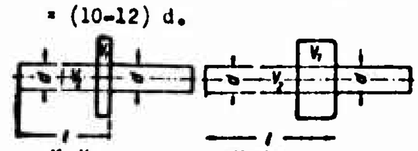


Table 25 (Continued)

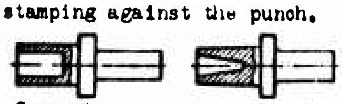
3. For formation of part in the form of a rod with flange (thickening) at the end or middle the volume of the flange V_1 does not have to exceed the volume of the rod V_2 of given diameter by length $l = (10$-$12)$ d.



$V_1 = V_2$, $l < (10 \div 12)d$ Correct

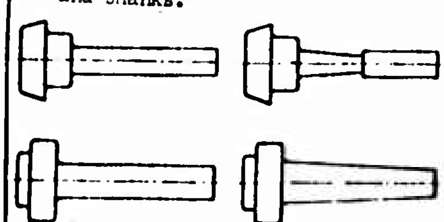
$V_1 = V_2$, $l > (10 \div 12)d$ Incorrect

4. To avoid reductions in longitudinal cross section of forging, constraining the flow of metal during stamping against the punch.



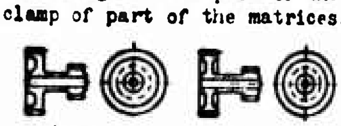
Correct Undesirable

5. To avoid conical form of grooves and shanks.



Correct Incorrect

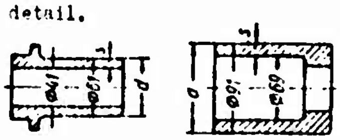
6. To avoid cavities on the face of the flange on the part of the clamp of part of the matrices.



Correct Undesirable

Table 25 (Continued)

7.	The thickness of walls of details with deep or unthrough holes it is desirable to make larger than 0.15 the external diameter of the detail.



Correct   Undesirable

Initial material for stamping on horizontal-forging machines is round, more rarely square, rolled products of chiefly heightened accuracy, and sometimes for hollow forgings also a blank in the form of seamless tubes. Stamping is done either from a measuring blank (usually for forgings, having the form of a rod with thickening) or "from a rod," i.e., from a blank, calculated by length for several forgings (usually for hollow forgings).

The volume of initial material $V_{\text{нс}}$ on one forging is determined by the volume $V_{\text{пк}}$ of a forging taking into account waste.

From volume $V_{\text{нс}}$ one should distinguish the upset volume $V_{\text{внс}}$, i.e., volume of the section of rod, coming from the clamp part of the matrices and subjected to deformation. The upset volume can be less than the entire volume necessary for obtaining the forging. Waste $V_{\text{ут}} \approx 1.5$-$2.5\%$ of the volume of the forging, on burr $V_{\text{з}} \approx 1$-2% of the volume of the upset section of the forging, are usual.

The diameter of the initial rod depends on the form of the forging. For forgings, having the form of a rod with thickening, the diameter of the initial rod is determined by the diameter of the rod.

For hollow forgings (ring, bushing and others) the area of cross section of the rod should be smaller than the minimal ring area of cross section of the forging. For thin-walled forgings the diameter of the rod d is obtained less than the diameter of the hole d_0, and for thick-walled – greater. For forgings with the ratio $\frac{D}{d_0} = 1.4$-1.6 (where D is the external diameter of forging) it is possible to take $d = d_0$.

Independent of the shape of the punch cavity or matrix it is possible to upset the end of the rod protruding from the clamp part of the matrix only in the case where the length of this end does not exceed 3 (better 2.5) diameters of the rod. If the length of the upset part is larger than the indicated magnitude, then preliminarily a set of material in the setting passes of the die intended for this is produced.

As an example in Fig. 53 the construction of the die is reduced to a horizontal-forging machine and the sequence of the technological process.

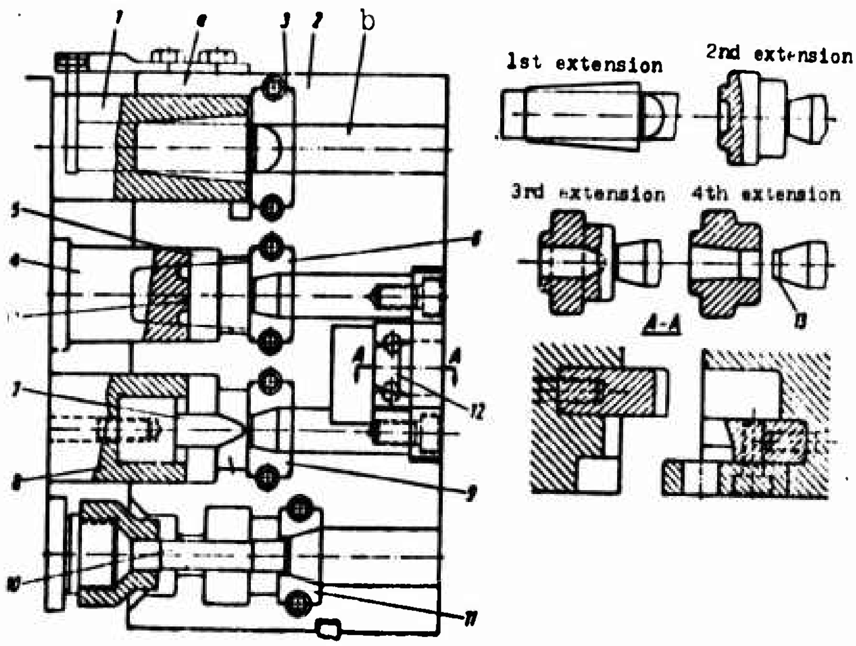


Fig. 53. Example of construction of a die to a horizontal-forging machine.

In the first pass a set of material in the conical cavity of the setting punch 1 is produced; front part a of pass 2 in the die directs the punch in the process of upsetting; the press part of the pass is the insert 3 which squeezes the initial rod in one direction, and the latter in place of squeeze gets an oval shape with a smaller diameter, approximately equal to the diameter of the hole in the

forging; clamp part 6 of pass 2 holds the rod in the process of upsetting.

In the second pass the upset punch 4 carries out preliminary molding of the forging in the upset cavity 5, where the protruding part 2 produces the initial marking of the future hole; the fullered insert 6 of the second pass produces fullering of the rod in the direction, perpendicular to the direction of action of the fullered insert 3 in the first pass, for which the forging during transmission of it from the first to the second pass turns around the axis by 90°.

In the third pass final molding of the detail is accomplished with almost through piercing of the hole by a pointed piercing punch 7 insertable in the basic punch 8. During piercing distribution of the material to the sides takes place, and the forging obtains final dimensions; the squeeze insert 9 of the third pass produces a final fullering, giving to the cross sections of the rod in place of a squeezed form the shape of an exact circle with a diameter of cylindrical section equal to the diameter of the hole in the forging.

The fourth pass is only piercing. The shape of the forging in it is not changed, hole is pierced right through with the help of a piercing punch 10 and piercing insert 11 in the die.

An additional detachable pass 12 in the die under consideration is the pass for cutting sections from the end of the rod of the cylindrical belt 13, constituting waste, which remains on the rod after piercing of the hole.

Dies with passes are fastened in the cheeks of the machine with the help of special cover plates. Dies can be by homogenous (for small machines) or compound (for large machines). Punches are fastened in punch holders, homogenous or compound, secured by cover plates in the slider of the machine.

The operating elements of the dies of a horizontal forging machine are made from alloy die steels (see Vol. 6, Chapter IV).

Stamping by Bending

Stamping by bending is carried out in one or several transitions depending upon the configuration of forging (Fig. 54). Passes of the die during bending on bulldozers are arranged one above the other (Fig. 55). During bending only internal radii are exactly obtained. Distortion of external contour occurs in even greater degree the smaller the internal radius with respect to thickness of the blank.

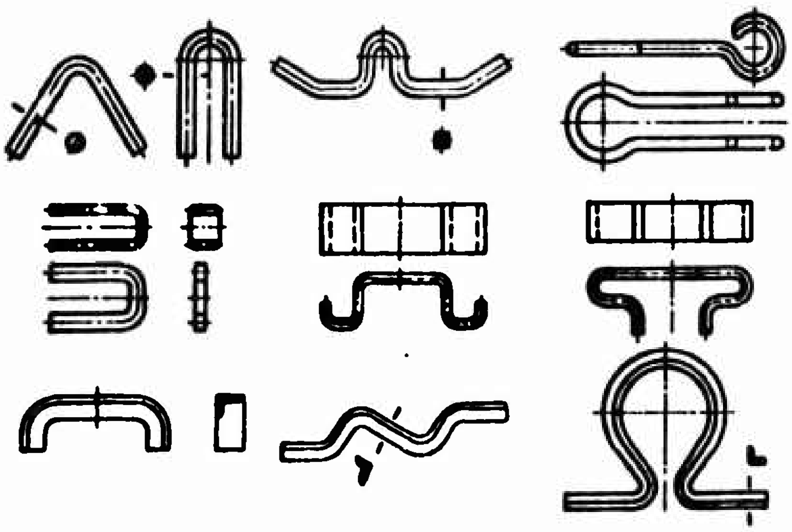


Fig. 54. Examples of forgings, prepared by bending [20].

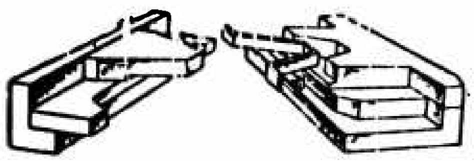


Fig. 55.

Bending sometimes is accompanied by additional operations (puncture of holes, cutting etc).

Stamping Rolling

Forging rollers have two rolls, revolving in opposite directions (Fig. 56); on rollers are fastened sector dies. The supply of the blank is produced at the time of divergence of the sector dies; the blank pressed in sectors simultaneously with pressing is ejected to the operating side.

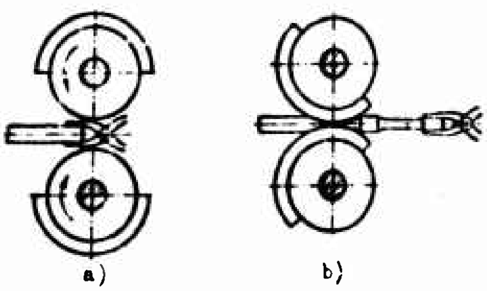


Fig. 56. Diagram of stamping in rollers: a) initial position; b) operating position.

The basic operation carried out on forging rollers, is drawing with assignment to the blank of a different shape (Fig. 57 and 58) both longitudinally and in cross section. Therefore, the area of cross section of the initial blank should be selected 10-15% larger than the maximum area of cross section of the forging [21]. Rolling of complicated forgings is accompanied by formation of a burr.

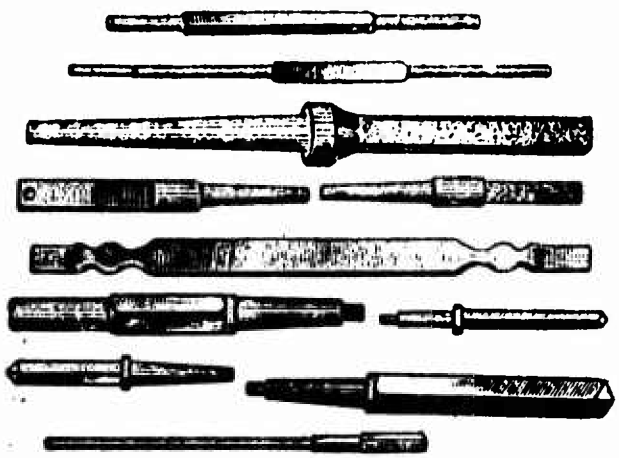


Fig. 57. Example of simple forgings obtained by roll forming.

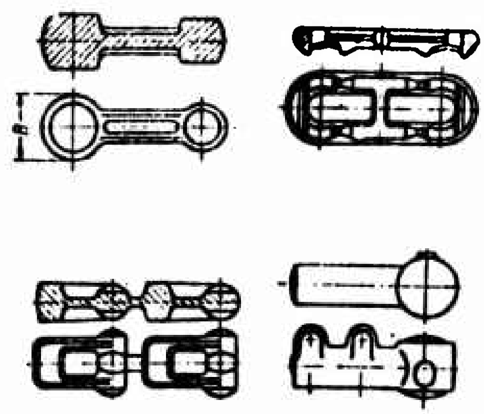


Fig. 58. Examples of complicated forgings, obtained by rolling.

Specialized Processes

Pressing on rotary-forging machines. The technological process, carried out on a rotary-forging machine constitutes drawing in shaped hammer blocks. The initial material is rods and pipes.

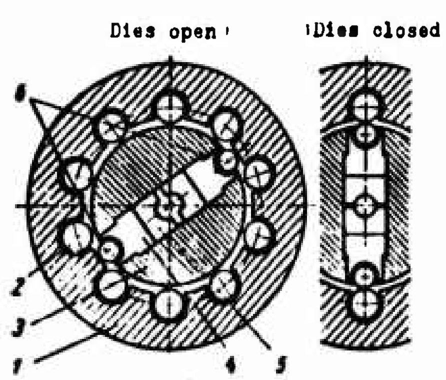


Fig. 59. Diagram of action of a rotary-forging machine.

The diagram of action of a horizontal rotary-forging machine is shown in Fig. 59. Sliders (hammers) 4, carrying hammer blocks can slip in radially located grooves of the head of the spindle 3. On the external faces of the sliders are support rollers 6. The head of the spindle 3 is located inside ring housing 1, in the

grooves of which the rollers 6 sit freely. During relative rotation of the casing 1 and spindle 3 the rollers 2 through rollers 6 will push sliders in the direction of the axis on closing of the dies 5.

In machines of the so-called first (the most wide-spread) type – with revolving tool – rotation is accomplished by a spindle 3, and the casing 1 is motionless. In machines of the 2nd (little wide-spread) type – with non-rotational tool, – conversely, casing 1 revolves with rollers 2, and spindle 3 motionless.

In machines of the 1st type reverse motion of the sliders occurs under the action of centrifugal force. In machines of the 2nd type for backward motion of sliders spring are used. The number of sliders is 2 or 4.

Final form after pressing on machines of the 1st type may be only a solid of revolution (Fig. 60), on machines of the 2nd type it is possible to obtain not only round, but also square, right-angle and other cross sections.

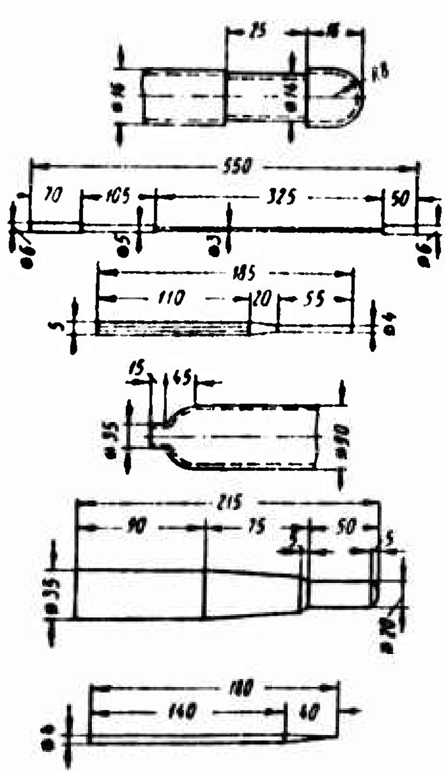


Fig. 60. Examples of forgings, obtained on rotary-forging machines.

Rolling. The initial blank for rolling is a ring, obtained by stamping on horizontal-forging machines or hammers.

The diagram of the process of rolling is represented in Fig. 61. Blank 1 jumps on roller 2. To it is brought a fast-rotating pressure roller 3. Blank 1 and roller 2 start to revolve. The internal and external diameters of the blank are

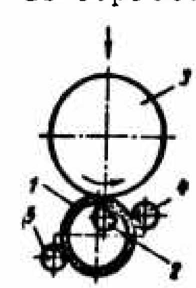


Fig. 61. Diagram of fuller.

increased, and the last one touches with the directional roller 4, which ensures obtaining of correct form for the blank. Rolling continues, while the blank is increased in diameter, does not touch the control roller 5. The beginning of its rotation conditions the removal of pressure roller 3 and ceasing of rolling.

Rolling allows obtaining of a forging of annular form (Fig. 62) with small allowances and tolerances [13], [19].

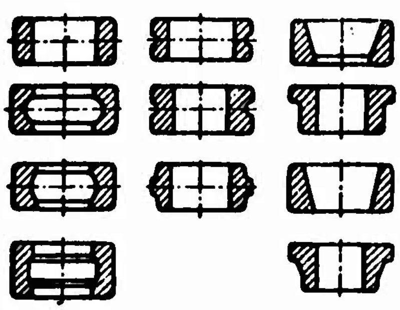


Fig. 62. Examples of forgings, obtained by rolling.

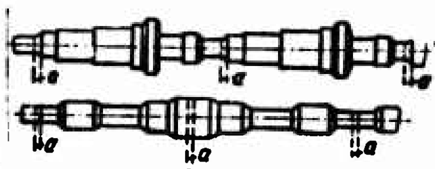


Fig. 63. Examples of forgings, obtained by transverse rolling (a – cutting places).

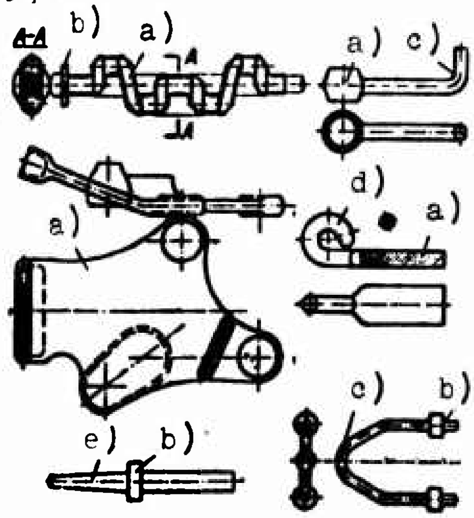


Fig. 64. Examples of forgings, stamped by sections by different methods: a) stamping in open dies; b) upsetting on a horizontal-forging machine; c) bending on a bulldozer; d) bending on a horizontal-forging machine; e) rolling.

Rolling. Rolling of teeth of gears is carried out on special tooth knurling machines, allowing conduct of the process by means of piece rolling or pile rolling [20].

Transverse rolling is a highly productive process of mass production of axially symmetric forgings of simple form (Fig. 63).

A combined process (Fig. 64) consists in obtaining of different sections of forging on separate machines, the most acceptable namely for obtaining of a given section. This process should be distinguished from the so-called differential or dismembered process when on various machines separate operations (for instance, stockpiling) of gradual formalization of the forging are carried out.

Finishing Operations

Cutting and stripping of a burr. A burr forming on a forging along the parting line during stamping in open dies is removed with the help of trimming dies, installed on cut crank presses.

Cutting may be carried out in the cold and hot state. In the hot state usually forgings, stamped on hammers with weight of incident parts over 1-1.5 m are cut. The cutting press in this case works coupled with a hammer.

The burr may also be internal, i.e., a crosspiece, obtained during marking of holes in the forging on stamping. For obtaining of a through hole the crosspiece is removed with the help of a piercing die.

The operations of cutting of an external burr and piercing an internal one can be carried out in one movement of the press in a combined die (Fig. 65).

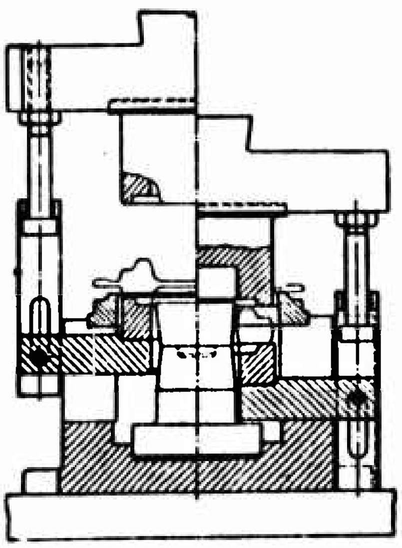


Fig. 65. Combined stamp.

Punches and dies are prepared from an alloy die, and also from carbonic tool steels (see Vol. 6, Chapter IV).

Unevenness of the cut after removal of the burr on a trimming die, and also insignificant burrs obtained during stamping on horizontal-forging machines and during stamping in closed dies are removed chiefly on grinding-stripping machines.

Dressing of stamped forgings. Forgings are dressed in hot or in cold state. Hot dressing is done after cutting of the burr without preheating either in a finishing pass of stamping hammer (in small-lot production) or in a special dressing die (in big-serial production) on a separate hammer

or crank press (big and complicated forgings), and also on a cutting press (average forgings).

Cold dressing is done in dressing dies usually on frictional hammers or presses after heat treatment (small and average forgings) [20], [24].

Sizing (stamping). With the help of sizing exact dimensions, surface of high quality and exact weight of forging can be obtained. Sized surfaces frequently do not require subsequent machining.

Sizing should be done on crank-elbow coining presses.

Sizing (clinching) can be distinguished as: plane, volume and combined.

A forging is subjected to plane sizing (Fig. 66) in the cold state for obtaining of exact dimensions between separate, chiefly parallel, planes of the body of forging and attachment to it of the proper quality of surface. Dimensions of the forging in directions perpendicular to the sizing direction are increased somewhat. Accuracy, which can be obtained as a result of plane sizing may be seen in Table 26. Cleanness of surface ∇4-∇6.

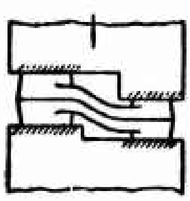


Fig. 66. Diagram of plane sizing.

In forging allowances for sizing have to be foreseen, the accuracy of its dimensions should be increased. It is necessary to consider that with an increase in allowance, for sizing the accuracy of dimensions after sizing decreases, and the quality of the surface is improved.

Table 26. Allowances for Dimensions Between Sized Surfaces of Details During Plane Cold Sizing [29].

Area of horizontal projection of sized surface in cm^2.	Allowances in mm (±)	
	Usual accuracy	Heightened accuracy
<3	0.1	0.05
3-10	0.15	0.08
10-20	0.2	0.1
20-40	0.25	0.15

Volume sizing serves basically for finishing of the surface of forging during simultaneous increase of accuracy of its dimensions and decrease of

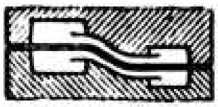


Fig. 67. Diagram of volume sizing.

fluctuation in weight. Volume sizing is done in a die (Fig. 67) with cavities, corresponding to the form of the forging and its required dimensions (Fig. 67). Here formation of a burr is possible to be removed on an emery machine. Accuracy of volume sizing is 30-40% lower than plane sizing.

It is possible to subject a forging to volume sizing in the heated state which significantly decreases the necessary press force. Accuracy and quality of surface besides will be lower.

Combined calibration consists in consecutive application of at first volume calibration, then plane.

The forging surface before sizing must be throughly cleaned of cinder by means of etching or shot-peening. Combined purification jointly by the methods indicated is desirable.

Preliminary preparation of forgings before sizing consists of cutting and stripping of the burr and purification of the forging from cinder by means of etching or tumbling either by shot-peening and a sand-blast apparatus. Combined purification of surface, i.e., etching and mechanical purification by one of the above-indicated is desirable.

SHEET METAL STAMPING

Peculiarities Sheet Metal Stamping

Advantages of sheet metal stamping as compared to other methods of treatment are the following: small weight of detail for high characteristics of durability and rigidity, low labor-consumingness of manufacture of detail, possibility of manufacturer of detail without further machining, high accuracy and interchangeability of parts economic use of metal.

Table 27. Characteristic of Seriality of Sheet Metal Production

Model criteria	Production			
	Mass	Bigserial	Small-series	Unit
Tentative annual output during one-shift work in thousands of pieces: for small parts for large parts	5000 300	100-5000 15-300	To 100 To 15	Units, tens, hundreds of pieces
Coefficient of seriality (number of operations, connected with pressing)	1-5 Continuous production with a coefficient of seriality equal to 1. For a large coefficient the size of the lot is determined depending on output production	5-15 Durability of the die is determined (from regrinding), but not more than a biweekly program	15-50 Small lots	- Unit parts
Makeup of equipment	Special presses, stamping automatic machines, automated and mechanized press	Automated and mechanized presses, stamping automatic machines, universal presses	Universal presses	
Types of dies	Combined, simple, dies automatic machines		Simple, simplified, plastic stamping by rubber	Universal, simplistamping by rubber, sheet metal dies
Degree of mechanization	Automated lines, mechanized flow lines, automatic feeding and yield	Automated lines, mechanized lines, flow lines, automatic feeding and yield, manual servicing	Manual servicing	

Note: In certain branches of machine building for individual and small-lot production of machines big-serial and even mass production of parts of these machines by the method of sheet metal stamping occurs, for instance, iron stator and rotor of generators and electric motors: transformer plates etc.: at the same time during big-serial production of articles in machine building, has small-lot production of parts occurs, which parts enter into these articles and are prepared by sheet metal stamping (machine-tool building).

Characteristics, of sheet metal stamping production depending upon its type as given in Table 27.

Selection of Material

For sheet metal stamping as the initial material ferrous and nonferrous metals and their alloys, and also nonmetallic materials are used. Stamping of flat details is done almost from any material: spatial parts, from material, possessing a definite degree of plasticity. The highest plastic properties of metal are necessary for deep drawing.

High capacity for drawing is possessed by steel with a carbon content 0.05-0.15%. Besides low content of carbon, the capacity of metal for drawing is characterized by equiaxialness and uniformity of magnitude of grains. The optimum size of grain for steel in a thickness s = 0.8-2.0 mm 26-37 μ ; s = 2-5 mm 37-52 μ , s = 5-6 mm 70-80 μ . Drawing of metal with coarse-grained structure gives a rough surface unfit for details, requiring a thin decorative covering and high quality of finishing. High quality of surface (without lines of shift) for drawing is ensured by non-aging steel 08 Yu; 08 Fkp; 08 Yups. The capacity of metal for drawing and other operations of stamping is determined by its mechanical properties and a technological sample. Basic indices of plasticity are relative length δ, transverse narrowing ψ, ultimate strength σ_B, yield point σ_T, ratio $\frac{\sigma_T}{\sigma_B}$ and hardness HRB. The larger δ, ψ and the greater the difference between σ_B and σ_T, the greater the plasticity of metal and the greater the form-change it is possible to produce. Hardness of sheet steel for deep drawing should be not more than HRB 36-48.

As example in Table 28 are given basic requirements for sheet steel, intended for making automobile parts by deep drawing.

Table 28. Basic Requirements for Sheet Steel for Automobile Parts

Parts	Ratio $\frac{\sigma_T}{\sigma_B}$	Elongation per unit length δ_{10} in %	Hardness HRB	Depth of extrusion h in mm.
Requiring very deep drawing and specially high finishing of surface (roof, wings, front panel and so forth)...........	0.6	44	38	0.7-1.0 above the GOST norm
Requiring deep drawing (doors and so forth)..........	0.65	44	40	0.5-0.7 above the GOST norm
Requiring deep drawing and allowing small defects of surface..............	0.70	40	40	According to GOST

Thin sheet metal qualitative construction steel both cold and hot-rolled may be divided into 3 groups according to capacity for rolling: DD – for very deep drawing; D – for deep drawing; N – for normal drawing. Indicators for each group are ultimate strength σ_B and elongation per unit length δ_{10}. Cold-rolled sheets have an elongation per unit length δ_{10} greater than hot-rolled ones. Steel of group DD includes brand 05-20; group D – 08-35; group N – 08-50.

Cold-rolled material is supplied with rigid tolerances on thickness and high quality surface. By the state of the surface this steel is divided into 4 groups: I – specially high finishing of surface, II – high finishing of surface, III – improved finishing of surface, IV – normal finishing of surface.

Cleanness of surface of a cold-rolled unpolished strip corresponds to the 7th class, but polished to the 8th and 9th class.

Usually the initial materials are supplied in the form of sheets, strips (thickness s ≤ 3.6 mm) and bands. Use of a strip s ≤ 2.5 is most effective in big-serial and mass production.

Qualitative and measured parameters for materials are determined by corresponding All-Union Government Standards and departmental standards.

Besides low-carbon steels, copper, brass, aluminum and magnesium alloys, stamping is used on molybdenum, cobalt and titanium alloys, and also stainless acid-resistant and heat-resisting steel Kh23N18, Kh23N28M3D3T, Kh25T, KhN78T, 1Kh18N9T and others. Great economic effect is attained by application of two-layered (plated) metal — low-carbon steels with plated copper, tin alloy, acid-resistant steel; brass — with silver and others.

Titanium alloys VT 1, VT 5 in cold state are stamped at a thickness of 0.8-2 mm, and with preheating to 500-600°C and greater thicknesses.

The sheet material "stilvetayt" which is a steel sheet with a covering of colored plastic (polyvinyl chloride) PVC, possessing at a thickness of 0.36 mm high resistance to wear, corrosion, the effect of acid, oils, and also dielectric properties, is stamped in usual dies without damage to the covering.

Of the nonmetallic materials those subjected to stamping are: paper; electric insulating, thermo-insulation and packing cardboard; fiber; laminated insulation; textolite; nekanite; celluloid; asbestos cardboard and paper; rubber, ebonite, technical leather, felt material; delta woodpulp, bakelite plywood and others.

Classification and Characteristic of Basic Operations of Sheet Metal Stamping

Form of treatment	Operation	Characteristics of operation
Cutting	Section	Full separation of one part of material from other by open contour.

(Continued)

Form of treatment	Operation	Characteristics of operation
Cutting	Trimming	Full separation of allowances or unnecessary material on articles, obtained by drawing, bending etc.

(Continued)

Form of treatment	Operation	Characteristics of operation
Cutting	Notching	Incomplete separation of one part oa material from the other.
	Stamping	Full separation of one part of material from the other by closed contour, where the separated part is the article
	Piercing	Full separation of one part of material from another by closed contour for obtaining of a hole
	Stripping	Full separation of small allowances or surpluses of material after cutting or puncture for obtaining of exact dimensions, smooth surfaces and sharp edges.
	Puncture	Formation in the material of a hole of this or another form, where the material removed from the hole is not separated completely, but is bent to the sides.

(Continued)

Form of treatment	Operation	Characteristics of operation
Bending	Bending	Attaching to the blank or half-finished product of bent form by a given contour, without application or with application of tension.
	Profiling of strip	Continuous transformation of strip into a given profile by consecutive bending on a roller machine or on special presses.
	Curling	Manufacture of an article in the form of a spiral, ring or some other configuration with respect to a curve by means of pressure on the rib of the blank.
Drawing	Drawing without thinning of material.	Transformation of flat blank into a hollow article or subsequent change of its form without conditioned changes in thickness of material.
	Drawing with thinning of material.	Transformation of a flat blank into a hollow article or subsequent change of its form with a given decrease in thickness of its walls.

(Continued)

Form of treat-ment	Operation	Characteristics of operation
Molding	Molding	Manufacture of parts from sheet and tubular blanks or half-finished products by means of local plastic flows without conditioned change of thickness of material.
	Distribution (stretching).	Formation in the hollow blank of a crater or increase in diameter of the blank in another place.
	Squeezing	Local decrease in diameter of the hollow blank
	Rolling	Formation in flat or hollow blanks of relief (ribs of rigidity and others) by special rollers on rolling machines or rotary shears.
	Flanging of holes	Formation of board by means of expansion earlier pierced hole.
	Sizing	Pressing of half-finished product for obtaining of required exact dimensions of detail.

(Continued)

Form of treat-ment	Operation	Characteristics of operation
Closed impression die forging	Dressing	Attaching to the article of required mutual location of its parts or regular surface (planeness).
	Pressing (cold extrusion).	Plastic deformation for which metal flows into the hole of the die or into a gap between the punch and matrix. Operation, ensuring the obtaining of details of complicated construction with thin walls.
	Clinching	Change of thickness or profile of the article with formation or without formation of relief on its surface.
Combined stamping	Operations in variously-shaped combinations.	Combination of several operations, carried out for one operational step of the press with the help of one or several dies fixed on one press.

(Continued)

Form of treatment	Operation	Characteristics of operation
Pressing operations	–	Transformation of a flat blank or half-finished product into a hollow solid of revolution rolled by rollers or other press tools on lathe-press machines, without conditioned change of thickness of material, or with change of thickness of material in given sections.
Assembly	Pressing	Joining of details at the expense of upsetting with interference or by means of free insert of one detail in other with subsequent deformation of one or both parts.
	Seaming	Joining of two or several details by means of a seaming lock, flanging, or folding.
	Winding	Joining of two or several parts from thin-sheet metal by means of bending of an edge by a given contour.
	Welding cold.	Nondetachable joining of details by means of plastic deformation of metal to joining of crystals.

Stamping of Flat Parts and Blanks

Cutting. Cutting of a sheet into strips, a wide strip into narrow ones, and also cutting by size or pattern is done by squaring or rotary shears (Table 28a) and usually is a preparing operation.

The force P, necessary for cutting of material using squaring shears with tapered blades, may be approximately calculated by the formula

$$P = 0{,}5\,\frac{s^2}{\operatorname{tg}\varphi}\,\tau_{cp},$$

where s is thickness of material; φ is angle of bevel of blade in degrees; τ_{cp} is resistance to cutting. For cutting on rotary shears, it is calculated by the formula

$$P_0 = 0{,}32 s^2 \tau_{cp} \cos 0{,}5\,\alpha,$$

where α is the angle of contact.

Allowances on width of bands cut on squaring shears are given in Table 29.

Table 28a. Method of Cutting of Sheet Metal and Strip Materials

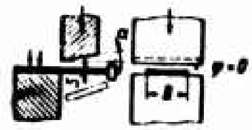
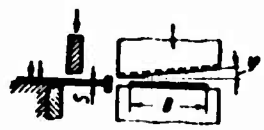
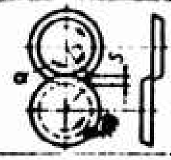
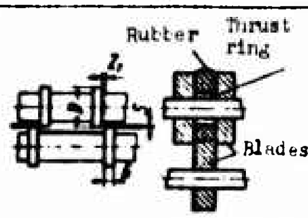
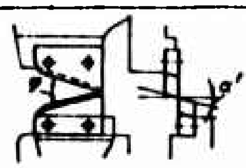
Type of shears	Diagram	Cut material
With parallel blades		Thin sheets, narrow strips in piece blanks, nonmetallic materials (cardboard, electric insulating material, laminated insulation, textolite and others)
With slanted blades		Sheet material in strips or piece blanks. Thickness of sheet to 42 mm. width to 4500 mm. (depending upon type of shears). Distortion after cutting of thick sheet metal is removed by dressing
Rotary with parallel axes		Sheets in bands, and also round (disk) blanks $s \leq 30$ mm. Least radius of cut blank for $s = 2.5$ mm is equal to 100 mm., for $s = 20$ mm., 450 mm. Speed of cutting from 5 m/min for thick material to 90 m/min for thin material
Rotary (with slanted blades)		Round and curvilinear blanks with small radius $r_{min} = 65$ mm for $s = 2.5$ mm and $r_{min} = 300$ mm for $s = 20$ mm. Speed of cutting 1.25-10 m/min
Multiple-rotary		Sheets and strips (in rolls) in bands and strips $s \leq 10$ mm. Speed of cutting 24 m/min. Quality of surface of cutting higher than on other shears. Ensure 7th class of accuracy. Rubber rings are for automatic feeding of thin metal
Vibration		Curvilinear blanks by marking or patterns, with small radius (to $r = 15$ mm.) $s \leq 10$ mm.

Table 29. Allowances on Width of Bands, Cut on Squaring Shears, Sizes in mm

Thickness s in mm	Width of bands						
	Up to 50	50—100	100—200	200—400	400—700	700—1000	1000—1500
	0.4	0.6	0.6	2.0	2.5	3.0	3.0
2—3	0.5	0.7	0.7	2.5	3.0	3.5	4.0
4—6	1.0	1.3	1.5	3.0	3.5	4.0	5.0
7—10	2.0	2.0	2.0	3.5	4.5	5.0	6.0
Up to 10 above 20	—	3.0	3.5	4.5	6.0	7.0	8.0

Cutting and puncture. By means of operations of cutting and puncture (Fig. 68 and Table 30) on presses by special dies it is possible to prepare flat part of the most varied structural shape. In the cold state from sheets of low-carbon steels

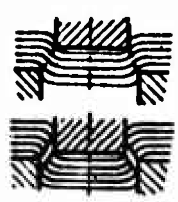


Fig. 68. Diagram of cutting and puncture by tool dies.

stamping is done for s ≤ 25 mm, and piercing for s ≤ 35 mm.

Table 30. Basic Methods of Cutting and Puncture by Steel Punches and Matrices

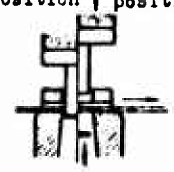
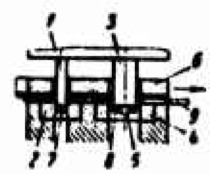
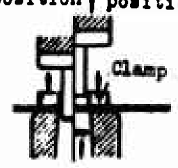
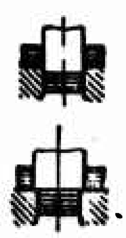
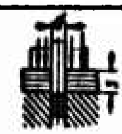
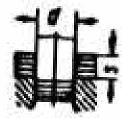
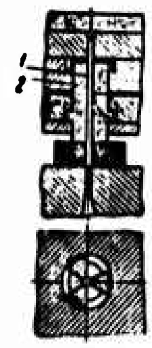
Methods	Diagram	Comparative technological characteristic
In dies of simple and consecutive action without a clamp		Stamped details have: Distorted surface (nonplanarity), least accuracy, cleanness of surface of cut: by conical part ∇ 1-3, by polished part ∇ 6-7. Method is highly productive. Convenient for automation:
		1 — breakthrough punch; 2 — breakthrough die; 3 — stamping punch; 4 — cutting die; 5 — catcher; 6 — stripper; 7, 9 — waste; 8 — article
In dies of simple and consecutive action with clamp		Ensures planeness, accuracy and cleanness of surface of cut, close to combined stamping. Method highly productive. Convenient for automation
In dies of combined action		Ensures planeness, high accuracy, cleanness of surface of cut in conical part ∇ 4-5. 1 — breakthrough punch; 2 — punch-die; 3 — cutting die; 4 — ejector; 5 — stripper; 6 — article; 7 — waste
Cutting: in a die with heaped up cutting edges; Punch by a larger dimensions than the die		Used for manufacture of small parts of complicated configuration, mainly from soft nonferrous metals. After getting out of die dimensions of part are increased by 0.02-0.05 mm. Accuracy of stamped details corresponds to the 3-4th class. For stamp stamping of parts of the gear type, the durability of the gear wheel is increased. A die with heaped up edges ensures a mirror surface of cut

Table 30 (Continued)

Methods	Diagram	Comparative technological characteristic
Puncture: with squeezing of blank to 60 kg/mm^2		d = 0.3 of 1.5 s Cleanness of surface of cut ∇6-7.
by a punch with heaped up edges		d $>$ 3 s. Cleanness of surface of cut is ∇8.
with telescopic direction of punch		d $\leq$ 0.3 s when s = 1.0 of 20 mm. Cleanness of surface of cut ∇7-8. 1 — breakthrough punch; 2 — directing bushing. Cleanness of surface of cut ∇7-8.

During cutting and puncture on the surface of separation of metal two zones (Fig. 69) are formed, the zone of polished belt with cleanness ∇6-8 and zone of dull, rough, conical (4-6°) surface of cleanness ∇1-4.

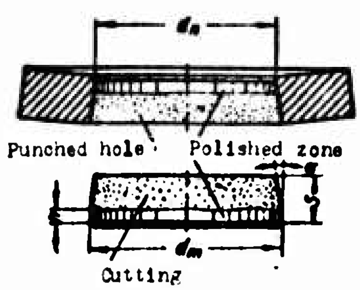


Fig. 69. Character of destruction of metal during cutting and puncture.

On the surface of separation of metal the hardness is increased by 100% and more. The depth of the hardened zone is 0.2-0.6 s to the side. Within the limits of the hardened zone, hardness is distributed nonuniformly, at a depth of 0.1 s the hardness sharply decreases. On a rough surface of the destroyed metal are formed micro-cracks.

In small-series and individual production cutting and puncture by rubber and explosive puncture are used. Explosive puncture is convenient during repair work in bridge and building constructions and for puncture of thick-walled plates.

Element-by-element stamping (Fig. 70) is used in small-serial and experimental production, basically for manufacture of large dimension details.

Stripping (Table 31) ensures 2-3rd class of accuracy and 7-8th class of cleanness of surface. Stripping usually is done on parts of thickness up to 5 mm, with dimensions in plan to 200 x 200 mm. After this operation the dimensions of the hole decrease for nonferrous metals to 0.005-0.01 mm, and for soft steels to 0.008-0.015 mm.

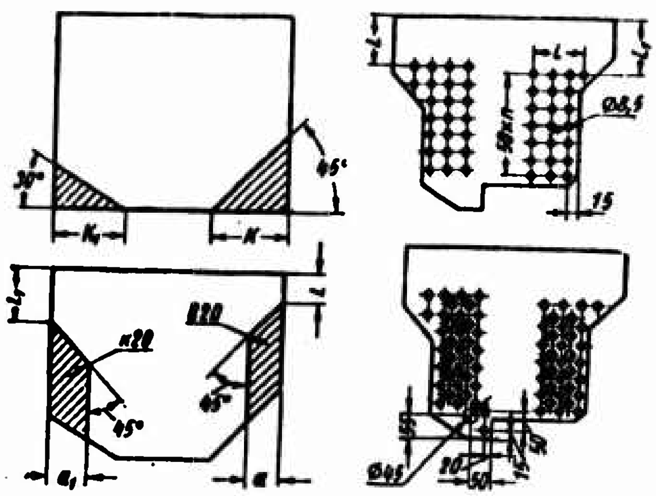
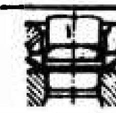
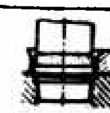
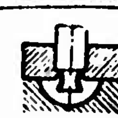


Fig. 70. Element-by-element stamping of large dimension parts.

Table 31. Basic Methods of Stripping

Cleaned surface	Methods	Diagram	Classes of cleanness of surface of cut
External contour	Cutting of allowance		7-8-th
	Pressing in cone die		7-th
Methods	Simultaneously with puncture (step punch).		7-8-th
			7-8-th

Technological requirements for construction of flat parts.

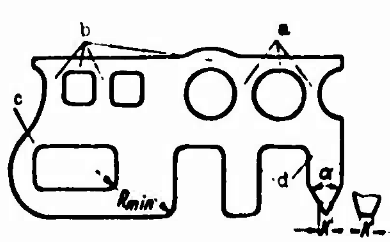


Fig. 71. Minimum dimensions between holes and contour of detail.

Arrangement of holes in parts and minimum dimensions between them, and, also, between holes and contour of part (Fig. 71), there must be values no less than the following:

$$a - \geq 0{,}7s; \quad b - \geq 0{,}8s; \quad c - \geq 0{,}9s; \quad d - \geq 1{,}5s.$$

Minimum external or internal angles α have to be:

for fragile materials

90° for $\sigma_{C} \geq 60$ kg/mm^2;

60° for $\sigma_{B} \leq 30$ kg/mm^2;

for plastic materials

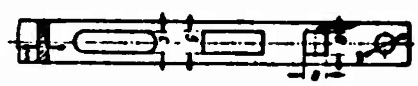
60° when $\sigma_{B} \geq 30$ kg/mm^2;

45° when $\sigma_{B} \leq 30$ kg/mm^2.

Smaller angles can be obtained during rounding of the apex $R_{min} \approx 0.5$ s or formation of square K ≈ s.

Minimum dimensions of pierced holes are given in Tables 32 and 33, and minimum radii of conjugation with rectilinear parts of contour stamped parts – in Tables 34.

Table 32. Minimum Dimensions of Holes, Pierced Tool Dies in Fractions of s



Material	Form of holes			
Steel $\sigma_B \leq 50$ kg/mm^2	d ≥ 1	0.9	0.8	0.7
Steel $\sigma_B = 50$-70 kg/mm^2	d = 1.3	1.2	1	0.9
Steel $\sigma_B > 70$ kg/mm^2	d = 1.5	a ≥ 1.3	b ≥ 1.2	c ≥ 1.1
Copper, brass	d ≥ 0.9	0.8	0.7	0.65
Aluminum, zinc	d ≥ 0.8	0.7	0.6	0.6
Laminated insulation, textolite	d ≥ 0.4	0.35	0.35	0.35
Paper, cardboard	d = 0.4	0.35	0.3	0.3

Note: Puncture of holes with ratio $\frac{s}{d} > 1$ may be carried out by punching with a directing bushing; the least diameter for hard steel is d = 0.5 s, soft steels and brass d = 0.35 s, aluminum d = = 0.3 s.

Table 33. Minimum Dimensions of Holes, Pierced by Rubber in Non-ferrous Alloys, in mm

Thickness of material s in mm	$P = 150$ kg/cm^2	$P = 100$ kg/cm^2			
	Hole and designation of dimension				
	Round		Square	Triangle isosceles	Curvature in angles
	Diameter		Smaller side	Side of the square	r
0.4	8	13	—	—	—
0.6	10	19	32	34	3
0.8	12	24	38	38	4
1.0	14	38	51	51	6
1.3	16	48	76	76	7

Table 34. Minimum Radii of Linkages of Straight and Curve Sections of Contour of Detail During Cutting and Puncture by Ordinary Dies

Operation	Angle of linkage	R_{min} in fractions of s		
		Copper, brass, aluminum	Steel soft	Steel constructional alloy
Cutting	≥ 90	0.18	0.25	0.35
	< 90	0.35	0.50	0.70
Puncture	≥ 90	0.20	0.30	0.45
	< 90	0.40	0.60	0.90

Table 35. Allowed Deflections During Cutting and Puncture

Thickness of material in mm.	from 0.2 to 1	above 1 to 3	above 3 to 6	above 6 to 10	above 10 to 20
Class of accuracy.	$\frac{A - A_9}{C - B_9}$	$\frac{A_2 - A_9}{C_1 - B_9}$	$\frac{A_3 - A_9}{C_2 - B_9}$	$\frac{A_4 - A_9}{C_4 - B_9}$	$\frac{A_4 - A_9}{B_8 - B_9}$

Note: Magnitudes of limiting deflections are taken for internal contour A-A_9, for external contour C-C_4 and B_8-B_9. Cleanness of surface may be obtained: for $s \leq 3$ mm $\nabla 7$-6; for s = = 3-6 mm $\nabla 6$-1; for $s > 6$ mm $\sim$.

Classes of cleanness 6 and 7 are obtained by stripping.

Cutting and puncture of details without linkage by radius is possible with use of compound punches and dies.

Allowed deflections in dimensions of parts, prepared by cutting, puncture and stripping, are given for machine building in Tables 35 and 36; for instrument-making, in Tables 37 and 38.

Table 36. Allowed Deflections of Dimensions Between Axes of Round Holes

Type of die	Dimensions between axes of holes in mm	Thickness of material in mm	Dimensions in mm: Deflection (±) for holes by diameter: Above 1 to 10	Above 10 to 30	Above 30 to 50	Above 50 to 80	Above 80 to 120
Combined high accuracy and cleaned	Above 6 to 30	Above 0.2 to 1	0,03	0,04	—	—	—
		» 1 » 3	0,04	0,05	—	—	—
		» 3 » 6	0,06	—	—	—	—
	Above 30 to 80	Above 0.2 to 1	0,04	0,05	0,06	0,07	—
		» 1 » 3	0,05	0,06	0,07	0,08	—
		» 3 » 6	0,07	0,08	0,09	—	—
	Above 80 to 180	Above 0.2 to 1	0,05	0,06	0,07	0,08	0,1
		» 1 » 3	0,07	0,08	0,09	0,1	0,12
		» 3 » 6	0,09	0,1	0,11	0,12	0,14
		» 6 » 10	—	0,12	0,14	0,16	—
	Above 180 to 360	Above 0.2 to 1	0,07	0,08	0,09	0,1	0,12
		» 1 » 3	0,09	0,1	0,1	0,12	0,14
		» 3 » 6	0,11	0,12	0,12	0,14	0,16
		» 6 » 10	—	0,14	0,15	0,17	0,19
	Above 360 to 63	Above 0.2 to 1	0,09	0,10	0,11	0,12	0,14
		» 1 » 3	0,11	0,12	0,13	0,14	0,16
		» 3 » 6	0,13	0,14	0,15	0,16	0,19
		» 6 » 10	—	0,17	0,18	0,2	0,22
Breakthrough (with clamp for thickness to 3 mm) curing simultaneous puncture of holes.	Above 6 to 30	Above 0.2 to 1	0,08	0,09	—	—	—
		» 1 » 3	0,09	0,1	—	—	—
		» 3 » 6	0,1	—	—	—	—
	Above 30 to 80	Above 0.2 to 1	0,1	0,11	0,12	0,13	—
		» 1 » 3	0,12	0,13	0,14	0,15	—
		» 3 » 6	0,14	0,15	0,16	—	—
		» 6 » 10	0,16	0,17	0,18	—	—
	Above 80 to 180	Above 0.2 to 1	0,12	0,13	0,14	0,15	0,16
		» 1 » 3	0,14	0,15	0,16	0,17	0,18
		» 3 » 6	0,16	0,17	0,18	0,19	0,20
		» 6 » 10	0,18	0,19	0,20	0,21	0,22

Table 36 (Continued)

Types of die	Dimensions between axes of holes in mm	Thickness of material in mm	Dimensions in mm: Deflection (±) for holes by diameter				
			Above 1 to 10	Above 10 to 30	Above 30 to 50	Above 50 to 80	Above 80 to 120
	Above 180 to 360	Above 0.2 to 1	0,14	0,15	0,17	0,18	0,22
		» 1 » 3	0,16	0,17	0,20	0,22	0,25
		» 3 » 6	0,18	0,20	0,22	0,25	0,28
		» 6 » 10	0,20	0,22	0,25	0,28	0,32
	Above 360 to 630	Above 0.2 to 1	0,18	0,2	0,22	0,25	0,28
		» 1 » 3	0,21	0,24	0,26	0,3	0,33
		» 3 » 6	0,25	0,28	0,30	0,35	0,38
		» 6 » 10	0,29	0,32	0,35	0,4	0,45
Breakthrough during separate punching of holes	Above 6 to 30	Above 0.2 to 1	0,30	0,35	—	—	—
		» 1 » 3	0,35	0,40	—	—	—
		» 3 » 6	0,40	—	—	—	—
	Above 30 to 80	Above 0.2 to 1	0,35	0,40	0,45	0,50	—
		» 1 » 3	0,45	0,50	0,55	0,65	—
		» 3 » 6	0,55	0,60	0,65	—	—
		» 6 » 10	0,65	0,70	0,80	—	—
	Above 80 to 180	Above 0.2 to 1	0,45	0,50	0,55	0,60	0,65
		» 1 » 3	0,55	0,60	0,65	0,70	0,75
		» 3 » 6	0,65	0,70	0,75	0,80	0,85
		» 6 » 10	0,75	0,80	0,85	0,90	1,0
	Above 180 to 360	Above 0.2 to 1	0,50	0,55	0,60	0,65	—
		» 1 » 3	0,60	0,65	0,70	0,80	0,90
		» 3 » 6	0,70	0,75	0,80	0,90	1,0
		» 6 » 10	0,80	0,85	0,90	1,0	1,10
	Above 360 to 630	Above 0.2 to 1	0,60	0,65	0,70	0,80	0,90
		» 1 » 3	0,70	0,75	0,80	0,90	1,0
		» 3 » 6	0,80	0,90	1,0	1,10	1,20
		» 6 » 10	0,90	1,10	1,15	1,20	1,40

Note: 1. For deviation between axes of holes less than 0.05 mm, and also in those cases, where a cylindrical surface is required for apertures of the class of cleanness must be above ∇6, the cleaning operation is necessary for materials of thickness over 1 mm.

2. Blanks of parts for dimentions with limiting deflection to 0.08 mm have to be subjected to preliminary dressing.

3. For holes of non-curved form, magnitudes of allowed deflections can be increased to 25%, depending upon the complexity of contour of the part.

4. Limiting deviations in dimensions between axes of punches must be for a combined die of high accuracy 40% and for breakthrough with simultaneous puncture of holes 45% of the magnitudes of limiting deflections of corresponding dimension between axes of holes of the part.

Table 37. Allowed Deflections of External Dimensions of Flat Details Dimensions in mm

Thickness of material	Die										
	Cutting of usual accuracy				Cutting heightened accuracy				Cleaning		
	Deflections for dimensions										
	Up to 10	10-50	50-150	150-300	Up to 10	10-50	50-150	150-300	Up to 10	10-50	50-150
0.2-0.5	0.08	0.1	0.14	0.2	0.025	0.03	0.05	0.08	–	–	–
0.5-1	0.12	0.16	0.22	0.3	0.03	0.04	0.06	0.10	0.012	0.015	0.025
1-2	0.18	0.22	0.3	0.5	0.04	0.06	0.08	0.12	0.015	0.02	0.03
2-4	0.24	0.28	0.4	0.7	0.06	0.08	0.10	0.15	0.025	0.03	0.04
4-6	0.3	0.35	0.5	1.0	0.10	0.12	0.15	0.20	0.04	0.05	0.06

Table 38. Allowed Deflections of Dimensions of Holes. Dimensions in mm

Thickness of material	Die							
	Breakthrough usual accuracy			Breakthrough heightened accuracy			Cleaning	
	Deviations for Dimensions							
0.2-1	0.05	0.08	0.12	0.02	0.04	0.08	0.01	0.015
1-2	0.06	0.10	0.16	0.03	0.06	0.10	0.015	0.02
2-4	0.08	0.12	0.20	0.04	0.08	0.12	0.025	0.03
4-6	0.10	0.15	0.25	0.06	0.10	0.15	0.04	0.05

Relationship Between Class of Accuracy of Stamped Details and Class of Accuracy of Manufacture of Punches and Matrices

Class of accuracy of stamped details	2-nd	2a	3-rd	4-th	5-th	7-th*	3-th
Class of accuracy of punches and matrices	80% 1-st	1-st	2-nd	2a	4-th	3a—4-th	4-th

* For s ≤ 6 mm class of accuracy 3a;
For s > 6 mm class of accuracy 4.

Stamping of Spatial Parts

Bending. Bending is used to prepare a part (Fig. 72) from wire, thin-sheet (s ≤ 4 mm), average sheet (s = 4-15 mm) and thick-sheet (s > 15 mm) rolling, and also from profiled blanks. Work is executed on universal sheet-stamping and special banding presses, on 3-4 roll bending machines, on bending automatic machines, jacketing and other bending machines. Multiangle bending in big-serial and mass production is carried out on special dies for one movement of the press, in small-lot production a multitransition method of bending on universal dies (Fig. 73) is used. In construction of parts it is desirable so that angles and radii (Tables 39 and 40) of curvature be identical, and it is necessary that access to the operating tool be ensured. On bending in material an elastic-plastic flow appears as a result of which hardening occurs and a spring appears (Table 41); the influence of the latter should be considered during construction of parts. The more plastic the metal, the less the angle and radius of bending; and the larger the thickness of blank, the less the spring. In order to decrease or remove the spring, bending with a clamp is used with calking, with drawing, and also ribs of rigidity in angles of bending will be anticipated.

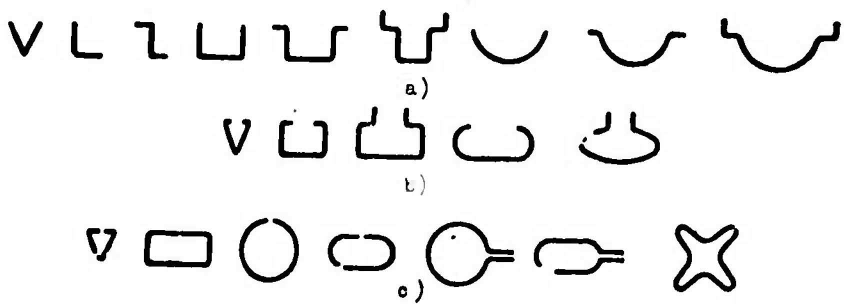


Fig. 72. Model profiles, obtained by bending: a) open; b) semi-enclosed; c) closed.

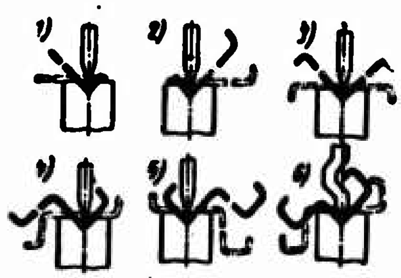


Fig. 73. Example of multitransition bending. Figures 1-6 designate number of transitions.

Table 39. Minimum Relative Radii of Bending ($\frac{r}{s}$)

Material	State of Material			
	Annealed or normalized		Riveted	
	Location of line of bend with respect to rolling fibers			
	Across	Lengthwise	Across	Lengthwise
Aluminum...........................			0.3	0.8
Copper.............................	0	0.3	1.0	2.0
Brass L68..........................			0.4	0.8
Steel 08 kp........................			0.2	0.5
Steel 08-10, St. 1, St. 2..........	0	0.4	0.4	0.8
Steel 15-20, St. 3.................	0.1	0.5	0.5	1.0
Steel 25-30, St. 4.................	0.2	0.6	0.6	1.2
Steel 35-40, St. 5.................	0.3	0.8	0.8	1.5
Steel 45-50, St. 6.................	0.5	1.0	1.0	1.7
Steel 55-60, St. 7.................	0.7	1.3	1.3	2.0
30KhGSA............................	4	8	—	—
Steel Ya1T, EI417..................	2	4	—	—
Steel KhN78T.......................	2.5	5	—	—
Steel Kh23N28M3D3T.................	2.0	4	—	—
Steel Kh25T........................	2.5	5	—	—
Duralumin soft.....................	1.0	1.5	1.5	2.5
Duralumin hard.....................	2.0	3.0	3.0	4.0
Magnesium alloys:..................	Heating to 300°		In cold state	
MA1................................	2	3	7	9
MA8................................	2	3	5	8
Titanium alloys....................	Heating to 300° to 400°		In cole state	
Vt1................................	1.5	2	3	4
VT5................................	—	—	4	5
Two-layered 20K + Kh18N12M2T (s = 20 mm, s = 5 mm)	2	3	—	—
Steel 10 — silver (s — 4 mm; s — 1 mm)	7.0	—	—	—

Notes: 1. Minimum radii of bending one should be used only in the case of absolute constructive necessity; in all remaining casses — use increased radii of bending.

2. For bending at an angle to the direction of rolling one should take average of intermediate values depending upon the angle of inclination of the line of bend.

3. In the case of bending of narrow billets obtained by punching or cutting without annealing; radii of bending must be selected as for cold-hardened metal.

4. For bending of thick sheets (above 8-10 mm) it is recommended that we use radii of bending of relatively large magnitude.

5. Bending a plating layer inside $R_{\Gamma} = 2s$; bending a plating layer, outside $R_{\Gamma} = 3s$.

Table 40. Least Radii of Bending of Profiles and Tubes

Profiles	Least radius of curvature	Note
Rolling: small... big....	4-5 h 8-10 h	Bending on three-roller machines. For bending in the free state the limiting radius of bend is significantly larger (25-50 h)
Thin-walled: symmetric asymmetric	8-10 h 20-25 h	Bending on special profile-bending machines
Steel bands (annular bend on a side)	3-4 h	Upper value for bending on roller machines
Steel pipes: s = 0.02 D s = 0.05 D s = 0.1 D s = 0.15 D	 4 D 3.6 D 3 D 2 D	Radius of bend along the axis of the tube. Bending without filler or mandrel. For smaller radii of bend, bending is done with a mandrel or filler

h — height of profile; D — diameter of tube; s — thickness of wall of tube.

Table 41. Magnitudes of Angles φ of a Spring at an Angle of Bend $\alpha = 90^\circ$ and ratio $\frac{r}{s} < 8$

Material	Ratio $\frac{r}{s}$	φ in degrees for thickness of material in mm		
		To 0.8	0.8 to 2	>2
Steel, $\sigma_B = 35$ kg/mm^2; Brass, σ_B up to 35 kg/mm^2; Aluminum, zinc	To 1	4	2	0
	>1 to 5	5	3	1
	>5	6	4	2
Steel, $\sigma_B = 40\text{-}50$ kg/mm^2; Brass, $\sigma_B = 35\text{-}40$ kg/mm^2	To 1	5	2	0
	>1 to 5	6	3	1
	>5	8	5	3
Steel, $\sigma_B = 55$ kg/mm^2	To 1	7	4	2
	>1 to 5	9	5	3
	>5	12	7	5
Heat-resisting steel YaIT; E1417; KhN78T	To 1	1		
	>1 to 5	4		
	>5	5		
Steel 30KhGSA	To 2	2		
	>2 to 5	4.5		
	>5	8		
Duralumin D-16		Annealed	Peened	
	To 2	2	4.5	
	>2 to 5	4	8.5	
	>5	6.5	14	
Duralumin D-95	To 2	2.5	8	
	>2 to 5	4	11.5	
	>5	7	19	

During bending on a narrow band (Fig. 74) its length is increased, thickness decreases and the profile of cross section is distorted. For a bandwidth greater than (20-30) s the profile is not distorted, but the thickness of the blank decreases.

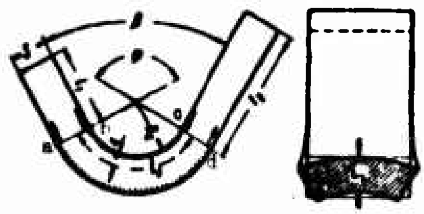


Fig. 74. Distortion of deformed section for bending of narrow band.

Section above abcd (Fig. 74) is divided by a nutral line l_3 into two zones. To the external side of the angle from line l_3 is located a stretched zone, but to the internal side, a compressed one. In the precess of bending, the neutral line is displaced to the internal side of the angle. Length of the reamer is determined by the sum of the straight sections of the detail and length of neutral lines of bent sections

$$L = l_1 + l_2 + l_3;$$
$$l_3 = \frac{\pi\varphi}{180}(R + X) = 0{,}017\,\varphi(R + X),$$

where φ is the angle of arc l_3 in degrees ($\varphi = 180 - \beta$); X is the distance from the internal plane to the neutral axis in mm, equal to $X = s'm$; the coefficient m is selected depending on the ratio $\frac{R_r}{s}$:

R_r/s	0,5	0,8	1	2	3	4
m	0,25	0,30	0,35	0,37	0,4	0,41
R_r/s	5	6	7	8	10	12
m	0,43	0,44	0,45	0,46	0,47	0,48

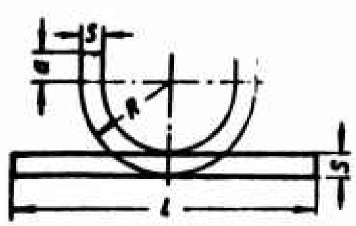


Fig. 75. Diagram of bending of the half-shell from thick-leaved steels.

In Fig. 75 a diagram is shown for bending of a half-shell made of thin-sheet carbon steel; (σ_B = 45-50 kg/mm^2) on a press of 2000 m. Length of blank (Fig. 75) is determined by the formula

$$L = \pi(R - 0{,}5s) + 2a.$$

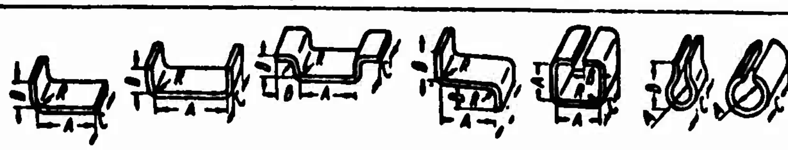
Table 42. Dimensions of Allowance a and Length L of Blank Depending Upon its Thickness and Width. Dimensions in mm

R	s	B	a	L
800	100	800	100	1600
1000	100	1000	150	2300
1500	120	2000	200	4400
2000	150	1500	300	6400

In Table 42 are given dimensions of allowance a and length of blank L depending upon thickness s and width B.

<u>Accuracy of dimensions for bending</u>. Allowed deviations in dimensions of parts, obtained by bending, in machines construction are given in Tables 43 and 44; in instrument-making – in Table 45.

Table 43. Allowed Deflections of Dimensions of Parts with Bending in mm (±)



C		Thickness of material		A				B			
above	to	above	to	to 50	50–100	100–250	250–700	to 50	50–100	100–250	250–700
–	100	–	1	0,3	0,4	0,5	0,8–1	0,5	0,8	1–1.5	1.5–2
		1	3	0,5	0,6	0,8	1–1.2	0,8	1	1.5	2–2.2
		3	6	0,6	0,8	1	1.2–1.5	1	1.5	1.5–2	2–2.5
		6	10	0,8	1	1.4	1.7–2	1	1.5	2	2.5–3
100	200	–	1	0.4	0,5	0,7	0,8–1.2	0,8	1	1.5	2
		1	3	0,5	0,6	0,8	1.0–1.5	1	1.5	1.5–2	2–2.5
		3	6	0,6	0,8	1	1.2–1.6	1	1.5	2.2	2.5–3
		6	10	0,8	1	1.2	1.5–1.8	1.8	1.5	2.5	2.5–3
200	400	–	1	0,5	0,6	0,8	1–1.2	0,8	1	1.5	2
		1	3	0,6	0,8	1.0	1.2–1.5	1.0	1.5	2	2.5
		3	6	0,8	1	1.2–1.5	1.8–2	1	1.5	2–2.5	2.5–3
		6	10	1	1.2	1.5–2	2–2.5	1.5	2	2.5–3.0	3.5
400	700	–	1	0,6	0,8	1	1.2–1.5	1	1.5	1.5–2	2
		1	3	0,8	1	1.2–1.5	1.5–2	1	1.5	2	2.5–3
		3	6	1	1.2	1.5–2	2–2.5	1.5	2	2.5–3	3–3.5
		6	10	1.2	1.5	2.5	2.5–3	2	2.5	3–3.5	3.5–4

<u>Note</u>: In columns with two values of deflections in dimensions – smaller deflections pertain to smaller dimensions.

Table 44. Allowable Deviation in Angles During Bending

Material of part	r/s		
	До 1	1–2	2–4
Steel, brass, σ_{cp} – 22 kg/mm^2	± 15'	± 30'	± 1°0'
Steel, brass, σ_{cp} – 35 ÷ 40 kg/mm^2	± 30'	± 1°30'	± 3°0'
Steel, σ_{cp} – 60 kg/mm^2	–	± 3°0'	± 5°0'

Table 45. Allowed Deflections During Bending Assumed in Instrument-Making

Thickness of material in mm	Linear dimension in mm			
	To 10	10–50	50–120	120–250
Dimensions, not shaped by die				
0.2–0.5	0.1/0.04	0.12/0.06	0.15/0.08	0.20/0.10
0.5–1	0.15/0.08	0.20/0.10	0.25/0.12	0.30/0.15
1–2	0.3–0.15	0.35/0.18	0.40/0.20	0.50/0.25
2–4	–	0.70/0.30	0.80/0.40	1.00/0.50
Dimensions, shaped by die				
0.2–0.5	0.1/0.04	0.12/0.05	0.15/0.06	0.20/0.08
0.5–1	0.12/0.05	0.15/0.06	0.20/0.08	0.25/0.10
1–2	0.15/0.06	0.20/0.08	0.25/0.1	0.30/0.12
2–4	–	0.25/0.1	0.30/0.12	0.40/0.16

Note: In every column on the left – allowance for heightened accuracy, on the right – for limiting attainable accuracy.

Bending with extension (Fig. 76) is used for manufacture of parts of large and average dimensions on picket and special expansible presses from steel, aluminum, magnesium and titanium alloys (dimension of sheets to 10, 000 x 2,000 x 6 mm). For simultaneous and nonsimultaneous with bending stretching of blank by 1-5% warping is removed, formed during rolling. Bending with extension significant accuracy is attained in manufacture of details by bending with drawing; springing almost is not observed.

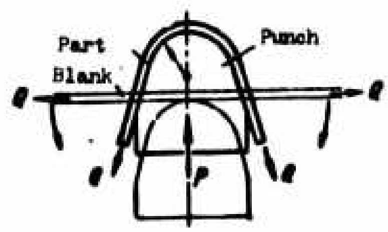


Fig. 76 Diagram of bending with extrusion.

Bending on roller profile-bending machines. Profiling of roll and strip metal (Fig. 77) on profilebending multiroller machines ensures obtaining of thin-walled parts and light rigid constructions of any configuration and length. Cold rolled strips of thickness up to 2.5 mm and bands of thickness up to 5 mm made of nonferrous metals and alloys, soft and stainless steel are subjected to profiling. Minimum radii during bending of profiles are given in Table 46. For airtightness of seam in a seam lock of closed profiles welding, soldering or covering by other metal is used. Productivity of profilebending multiroller machines reaches 15-75 m/min.

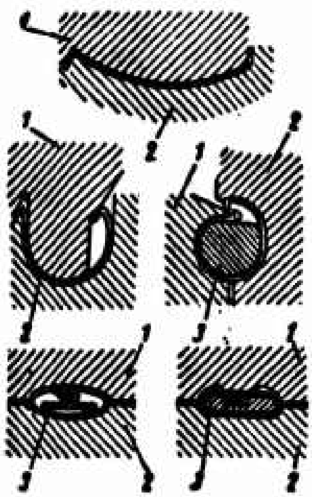


Fig. 77. Diagram of profiling by rollers: 1-2 – rollers; 3 – mounting.

Table 46. Minimum Dimensions of Radii of Curvature of Bent Profiles

Thickness of material in mm	Minimum radius of bend in mm	Allowance by radius
0.3–0.6 0.8 1.0 1.2	2.0 3.0 3.5 4.0	± 0.5 mm
1.5 1.8–2.0 2.5–3.0 4.0 5.0	5.0 6.0 9.0 12.0 15.0	± 10% of dimension of minimum radius of bend

Bending of profiled blanks. During bending of profiled blanks it is necessary to consider hardening and rigidity of profile.

For preventing of distortion of thin-walled profile of great curvature (small radius) bending is done on special machines with clamp, with flexible insert of filler. Bending of long thin-walled profiles with large radius is done by patterns with simultaneous axial extension of profile.

This method is used for removal of elastic deformations.

Drawing. Drawing (Table 47 and 48) is used to make hollow thin-walled parts of various form (Fig. 78): axially symmetric (solid of revolution, box-like form), with one axis of symmetry and asymmetric.

Parts which are asymmetric and with one axis of symmetry are the most complicated in construction and technology of manufacture.

Table 47. Basic Methods of Drawing

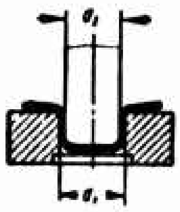
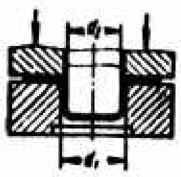
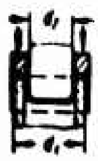
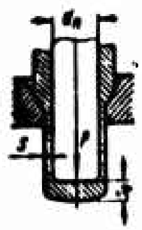
Drawing	Diagram	Region of application and characteristics of process
Without clamping of blank		Shallow drawing of thin material and deep – for comparatively large thickness of material. For 1st drawing $\frac{d_1}{D} \geq 0.55$ and $s \geq 0.017D$. For 2nd drawing $\frac{d_2}{d_1} \geq 0.78$ and $s \geq 0.015D$. D – diameter of blank
With clamping of blank		Deep drawing. For 1st drawing $\frac{d_1}{D} < 0.6$ and $s \leq 0.015D$. For 2nd drawing $\frac{d_2}{d_1} \leq 0.78$ and $s \leq 0.01D$. For presses of simple action the die is located above, the punch and clamp below
Reverse		For very deep drawing and for drawing of double-walled hollow parts of big and average dimensions with a relative thickness of blank $\frac{s}{D} \cdot 100 > 0.25$. For one operation a part can be obtained $h \leq 0.25d$ in height; d – external diameter of part. During drawing from aluminum alloys with preheating of flange, after one operation can be obtained $h = 0.6\text{-}1.0d$. Double-walled hollow details of small dimensions from nonferrous metals better to stamp by pressing by direct, inverse or combined procedures
With thinning		Manufacture of very deep articles (cases, bellows, parts with thin walls and thickened crater and so forth) with given, unequal thickness of walls and bottom $\frac{s}{s_0} - \frac{1}{10} \div \frac{1}{20}$. Such a ratio of thickness of walls and blank is attained by multiple or simultaneous drawing through several matrices.

Table 48. Special Methods of Drawing

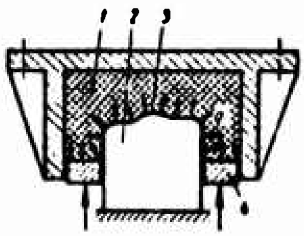
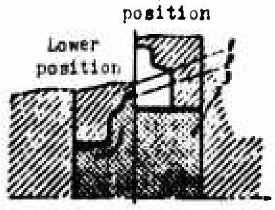
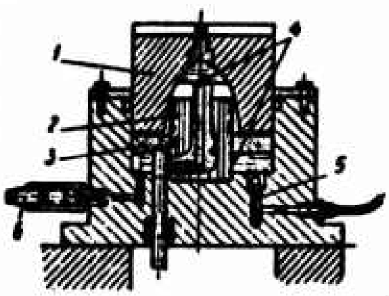
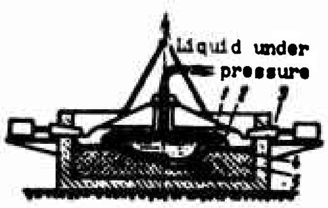
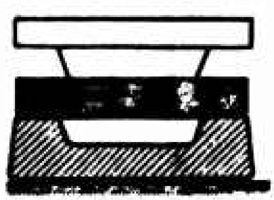
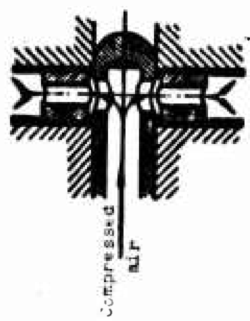
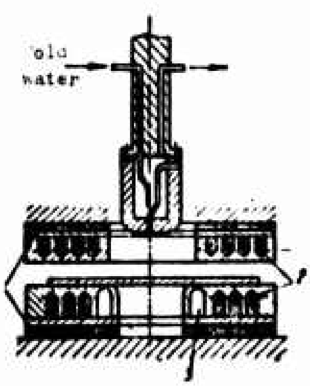
Drawing	Diagram	Region of application and characteristic of process
Rubber		Small-lot production. Shallow drawing of aluminum, magnesium alloys, low-carbon steels of thickness to 1-1.5 mm with a pressure of rubber 50-85 kg/cm^2. Deep drawing of any material with high pressure of rubber (to 500 kg/cm^2). Drawing of parts of complicated configuration 1 – rubber; 2 – punch; 3 – stamped detail; 4 – clamp
Lead		Small-lot production of parts from light alloys. Ensures deeper drawing than drawing by rubber. After every drawing lead is settled to initial position 1 – die; 2 – stamped detail; 3 – punch (lead)
Hydraulic on press		Serial and small-lot production of hollow parts of complicated form from thin-sheet metal (aluminum alloys, stainless steel) 1 – die; 2 – punch; 3 – clamp; 4 – liquid; 5 – pressure valve; 6 – safety valve
Hydraulic without press		Small-lot production of parts of large dimensions from thin-sheet metal (aluminum alloys, stainless steel) 1 – cover; 2 – rubber case; 3 – closing wedge; 4 – stamped part; 5 – nonmetallic die
Drawing formation on hammers (cast dies and plywood rings)		Small-lot production of big parts from aluminum alloys in thickness to 4 mm, and soft steels of thickness to 2 mm

Table 48. (Continued)

Drawing	Diagram	Region of application and characteristic of process
On Covering hydraulic presses		Small-lot production. Drawing-molding of big parts with smooth transitions by means of covering of thin-sheet metal (aluminum and magnesium alloys, stainless and carbon steel) by metallic or wooden punches.
Drawing formation by compressed air		Shallow drawing-molding of parts from thin-sheet aluminum alloys simultaneously with plastic welding of edges.
With preheating of flange		For metals with lowered plasticity in cold state, for instance magnesium alloys of Ma-1, Ma-8 and titanium alloys 1 — thermoinsulating linings; 2 — electric heaters; 3 — chamber for compressed air.

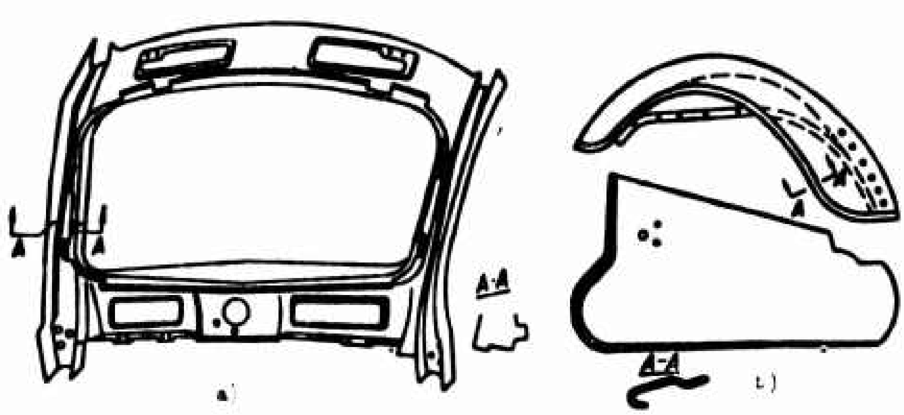


Fig. 78. Examples of stamped details of complicated construction: a) with one axis of symmetry (internal front panel of automobile); b) asymmetric (fender of automobile).

<u>Technological requirements for construction of details</u>. Radii of of linkages of bottom and flange with walls of hollow cylindrical parts should be taken from Table 49 (tool die). Radii of curvature can be decreased at the expense of additional operations, so-called upsetting of radius. Linkages of walls and bottom by radius (Fig. 79a) are used for parts in diameter up to 60 mm. For large diameters it is better to use linkage conically at an angle of 45° (Fig. 79b).

Table 49. Radii of Linkages of Bottom and Flange with Walls of Cylindrical Parts Depending Upon Thickness of Material

Radius of linkage in mm	Thickness of material in mm					
	До 1	1–2	2–3	3–4	4–5	5–6
For bottom	2	3	5	6	7	8
For flange	3	5	6	7	8	10

It is necessary to avoid construction of details with deep cavity and wide flange, requiring large quantity of operations. Depth of drawing of right-angle box-like details on first operation depends on ratio $\frac{H}{R}$.

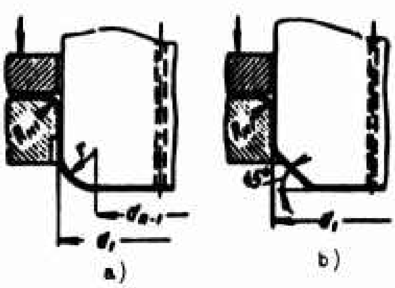


Fig. 79. Diagram of linkage of bottom and with walls of cylinder.

Material	$\frac{H}{R}$
Steel pickled.........................	4-4.5
Steel thin-sheet cold-rolled...........	5-6
Copper, brass L62 and L68..............	5.5-7
Aluminum, aluminum magnesium alloy AMts	5.5-6.5
Duralumin D16M.........................	4-4.5

where H is the depth of drawing; R is the radius of curvature in angular sections of the box.

Tentatively depth of first drawing rectangular parts may be taken as follows:

Radius of curvature R in mm	4-6	6-10	10-16	16-20	20-25
Depth of drawing H in mm...	20	35	50	75	100

Accuracy of dimensions during drawing. Allowed deviations in dimensions of parts, obtained by drawing for soft steels and brass, are given in Tables 50 and 51.

Table 50. Allowable Deviations in Diameter of Cylindrical Parts Without Flanges. Dimensions in mm (±)

Thickness of material	Diameter of extruded part		
	To 50	50–100	100–300
0,5	0,12	—	—
0,6	0,15	0,20	—
0,8	0,20	0,25	0,3
1,0	0,25	0,30	0,4
1,2	0,30	0,35	0,5
1,5	0,35	0,40	0,6
2,0	0,40	0,5	0,7
2,5	0,45	0,6	0,8
3,0	0,50	0,7	0,9
4,0	0,60	0,8	1,0
5,0	0,70	0,9	1,1
6,0	0,80	1,0	1,2

Table 51. Allowances of Cylindrical Hollow Parts with Respect to Height. Dimensions in mm

Thickness of material	Allowance (±)* for a height of extruded detail						
	To 18	18–30	30–50	50–80	80–120	120–180	180–260
To 1	0,5/0,3	0,7/0,4	0,8/0,5	1,0/0,6	1,2/0,8	1,5/1,0	1,8/1,2
1 To 2 ..	0,6/0,4	0,8/0,5	1,0/0,6	1,2/0,7	1,5/0,9	1,8/1,2	2,0/1,4
2 » 4 ..	0,8/0,5	1,0/0,6	1,2/0,7	1,5/0,8	1,8/1,0	2,0/1,4	2,5/1,6
4 » 6 ..	1,0/0,6	1,2/0,7	1,5/0,8	1,8/0,9	2,0/1,1	2,5/1,6	3,0/1,8

*In numerator — for part without cutting, in denominator — for parts with flange.

Drawing with thinning. Calculation of thickness of walls during drawing with thinning may be done by the formula

$$K_n = \frac{F_n}{F_{n-1}} \cdot 100 \approx \frac{s_n}{s_{n-1}} \cdot 100,$$

where K_n is the coefficient of drawing (see Table 52); F_{n-1} and F_n are the area of cross section before and after drawing in mm^2; s_{n-1} and s_n are the thickness of wall before and after drawing in mm.

Table 52. Mean Values of Coefficient K_n Drawing by More Precise Definition in %

Material	K_n for drawing	
	First	last
Steel soft	[illegible]–40	[illegible]–[illegible]
Steel of average hardness.	65–60	75–70
Brass	[illegible]–40	80–[illegible]
Aluminum	40–35	[illegible]–[illegible]

Drawing with preheating of flange allows stamping of a part with depth of drawing exceeding by 2 times and

more the depth of drawing, obtained at room temperature. One operation of drawing with preheating of flange replaces 3-6 operations of drawing at room temperature. Hollow parts from magnesium alloys can be obtained only by drawing with preheating. Optimum temperature of heating of a flange from certain materials are as follows in $^{\circ}C$:

AM, AMtsM, D16AM	310-330
MA1, MA8	360-380
D16AT, V95AT, L62	400-420
Steel 08$\text{к}_{\text{п}}$ and pickled	550-580
Titanium alloys	650-700

Molding. Molding is used for formation of ribs of rigidity and small deepenings of various configurations. The limit of possible deformation of metal (Fig. 80) is found from expression

$$\frac{l_1 - l}{l}\cdot 100 < \delta,$$

where l_1 is the reamed length by section of relief in mm, l is the distance between extreme axes of relief; δ is the elongation per unit length of metal in %.

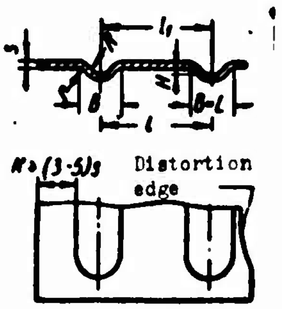


Fig. 80. Molding or ribs of rigidity. Dimensions are recommended for ribs of rigidity: r = = 2-5 s; R = 5 s; R = 5-15 s; B = = 10-25 s; H = = 5-15 s.

Flanging by hole (Fig. 81) is used for obtaining of a hole of large diameter, an edge, decrease of weight and increase or rigidity of parts.

The diameter of a hole under flanging is determined by the formula

$$d = D_{cp} - 2(H - 0{,}43R + 0{,}72s).$$

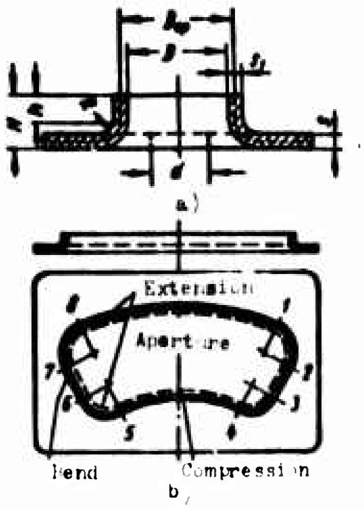


Fig. 81. Flanging of holes: a) round; b) complicated contour.

The height of an edge may be approximately calculated by the formula

$$H = \frac{D_{cp} - d}{2} + 0{,}43R + 0{,}72s.$$

The radius of curvature R is recommended for material of thickness to 2 mm R > 2-3 s, over 2 mm R ≥ 1.5-2 s. The coefficient of flanging $K = \frac{d}{D_{cp}}$ for low-carbon steels one should take as 0.70-0.85.

<u>Pressing (extrusion)</u>. Pressing (Figs. 82 and 83) in cold state is used mainly for nonferrous metals and their alloys (A00, AV1, AV2, D1, M1, M2, M3, Ts0, Ts1, Ts2, L62, L68, bimetalic and plated materials), and also low-carbon and low-alloy steels (08, 10, 15, 18KhGT and others).

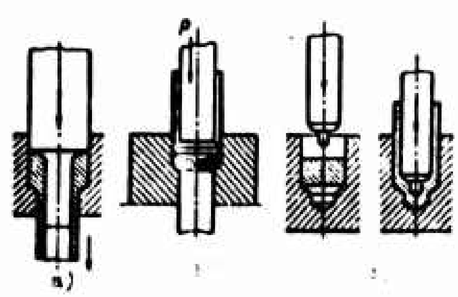


Fig. 82. Methods of pressing: a) direct; b) reverse; c) combined.

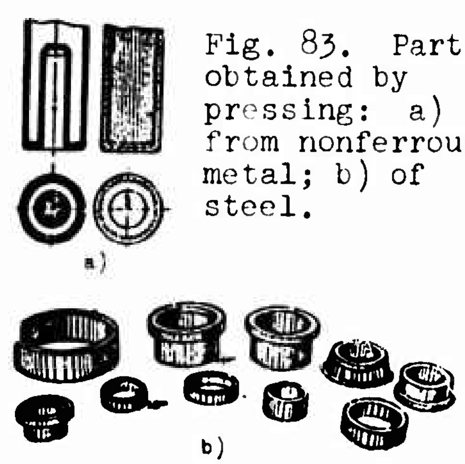


Fig. 83. Parts obtained by pressing: a) from nonferrous metal; b) of steel.

In Tables 53 and 54 are given dimensions and accuracy of manufacture of details from nonferrous metal by pressing. Cleanness of surface attains 9-10th class. Cold pressing is widely applied in radio- and instrument-making, perfumery and other branches of industry, replacing up to 8 operations of drawing and lowering by many times the labor-consumingness. By pressing (cold pressing) of steel a part can be made in length from 5 to 1200 mm, diameter 5-150 mm

with thickness of walls from 0.1 to 50 mm. Allowances for dimensions of details are given in Table 55.

Table 53. Dimensions of Parts, Prepared by the Method of Cold Direct Extrusion in mm

Dimensions	Lead, tin, zinc, aluminum		Duralumin, copper, brass		Accuracy of manufacture in mm (±)
	From	To	From	To	
Diameter (cylindrical details)................... Section (rectangular details)..................	3 2 × 4 0,05	100 70 × 80 0,1 and larger	5 3 × 5 0.3 (brass) 0.5 (copper)	100 70 × 80 1,0 and larger	0,03—0,05 0,03—0,05 0,03—0,075
Thickness of flange........	0,2—0,3	0.5 and larger	Equal to thickness of walls	Larger than thickness of wall	0,05—1,0
Length of detail..........	5 d	60 d	3 d	40 d	1—5

Table 54. Dimensions of Parts, Prepared by Method of Reverse Cold Extrusion in mm

Dimensions	Lead, tin, zinc, aluminum		Duralumin, copper, brass		Accuracy of manufacture in mm (±)
	From	To	From	To	
Diameter (cylindrical details).................. Section (rectangular parts) Thickness of walls.........	3 5 × 7 0,06	100—150 70 × 80 0,23 and larger	10 6 × 9 0,5 (copper) 1.0 (brass)	50—70 20 × 40 1,0 and larger	(0,03—0,05) (0,03—0,05) (0,03—0,075)
Thickness of base..........	0,25—0,3	0,5 and larger	Equal to thickness of walls	Larger than thickness of walls	(0,10—0,2)
Ratio of length of detail to diameter................	3 : 1	10 : 1 (lead) 8 : 1 (aluminum)	3 : 1	5 : 1	(1—3)

Table 55. Allowances for Dimensions of Steel Parts During Cold Extrusion

Dimensions of detail in mm	Allowances in mm (±)	
	normal	heightened
Diameter 10—70 70—100 100—150	0,1 0,2—0,3 0,4—0,5	0,02—0,03 0,04—0,06 0,06—0,12
Thickness of wall 1,0—1,2 1,2—3,5 3,5—6,0	0,07—0,10 0,1—0,15 0,15—0,2	— — —
Uncoaxialness	0,5—12% from D	

Construction steel parts must be done in such a way that during their manufacture by extrusion the following is not allowed:

a) multiple sharp change of cross sections;

b) stepped shapes with small drop of external and internal diameters;

c) ribs of rigidity;

d) asymmetric thickenings;

e) small radii.

Drafts are not assigned. Details, prepared by pressing from low-carbon steel, can replace parts from low-alloy steels or thermally treated parts prepared by other methods.

The economically expedient quantity of details, prepared by extrusion on universal and special equipment tentatively is given in Table 56.

Table 56. Number of Parts Prepared by Extrusion Depending Upon Their Weight and Equipment

Weight of part in kg	Equipment	
	Universal	Special
0,001–0,02	10 000	500 000
0,02–0,500	5 000	100 000
0,5–10	3 000	80 000
10–35	1 500–10 000	10 000–50 000

Press operations. In unit and serial production, when manufacture of dies is economically unprofitable, and also for obtaining of hollow parts of convexo-concave form with walls of variable thickness from aluminum and copper alloys, carbonic and stainless steel, molybdenum, titanium alloys and other materials, press operations are used. In doing this the process can flow without causing change of thickness of material (Fig. 84a) and with change of it (Fig. 84b).

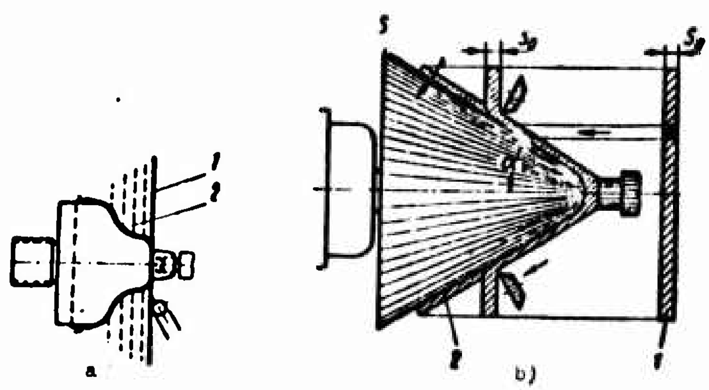


Fig. 84. Diagram of process of extrusion; a) without change of thickness of wall; b) with change of thickness of wall; 1 – blank; 2 – ready detail.

For blanks we can use: sheets, tubes, casting, welded blanks, forging with preliminary machining (Figs. 85 and 86). Sheets of aluminum and copper alloys are processed with thickness to 38 mm; from soft steels – to 25 mm; from stainless steel – to 20 mm

in cold state; titanium alloys are processed with preheating to 590°C.

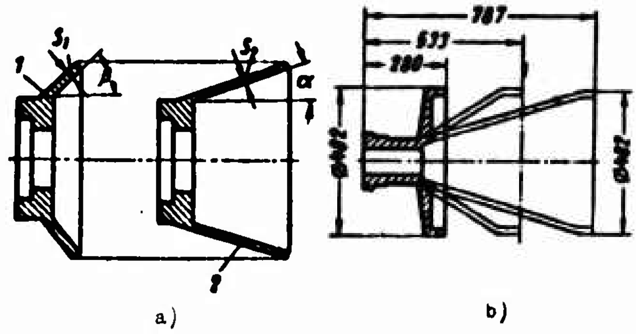


Fig. 85. Diagram of process of pressing with rolling; a) forged blank; b) forged blank with bored cup in it; 1 – blank; 2 – part.

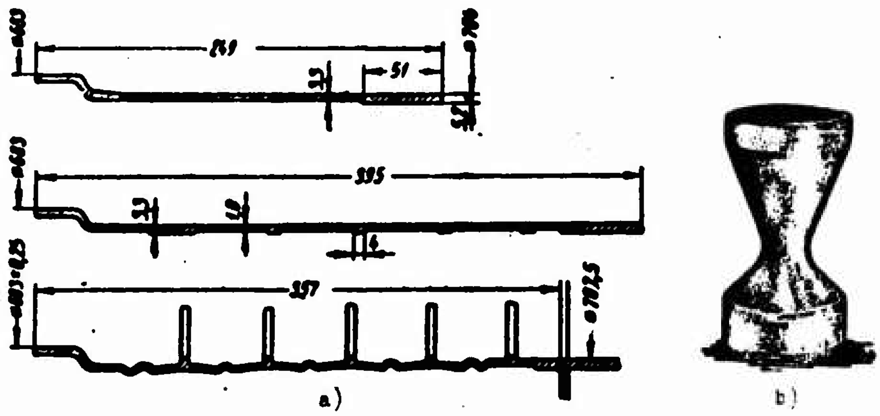


Fig. 86. Diagram of process of extrusion from a blank of tubular form: a) housing of crankcase; b) nozzle of molybdenum pipe.

Details of small dimensions from thin and plastic metal are obtained by pressure from a wedge manually or by means of supply of support on a revolving blank. Pressing of details of large dimensions (diameter to 1100 mm and more and length to 1270 mm) and of significant thickness is done on press-rolling machines by means of rollers, attached to the support of the machine. For mechanization of work on press or lathes a power head (with press tool) may be used secured to the support. The specific pressure on the metal reaches 280 kg/mm^2.

Manufacture of parts of cylindrical form on press machines is done for a ratio $\frac{d}{D} = 0.6-0.8$, where d is the diameter of detail, and D is the diameter of blank; conical shapes with a limiting ratio $\frac{d_{min}}{D} =$ $= 0.2-0.3$; d_{min} is the least diameter of the cone.

The least angle, which may be obtained during manufacture of conical details, $\alpha = 30^{\circ}$. The thickness of walls of a part depends on the angle of conicity $s = s_0 \sin \alpha$.

Table 57. Accuracy During Press Operations

Measured dimension	Allowance in mm (±)	Cleanness surface in μ
Thickness of wall	0.05	
Internal diameter:		
to 150 mm.......	0.05	0.15-0.20
more than 150 mm	0.075	
Length...........	0.12	

Thinning can reach 75% of the thickness of the initial material. After treatment on a press-rolling machine σ_B sharply increases. After annealing σ_B approximately by 40% higher than in initial metal. Accuracy during press operations appear in Table 57.

Technology of Stamped Parts

For construction of details for manufacture by sheet stamping and appraisal of their technology, it is necessary first of all to consider stability and dimensions of the detail, and also the scale of production. For frequent replacement of objects of production one should avoid constructions requiring deep drawing and complicated technological equipment. Deep drawing of parts of large dimensions should be used in the case where they carry large load or the scale of production allows large expenditures on technological equipment. When scale of production is small, complicated parts or parts of large size are dismembered into several parts combinable by welding;

pressing on press-rolling machines, or stamping by explosion and so forth are used. Special attention during construction of a part should be allotted economic use of material and guarantee of high productivity of stamping (Table 58 and 59).

Table 58. Examples of Constructional Changes of Stamped Parts Increasing the Technologicness of Structure

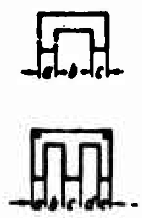
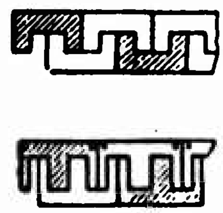
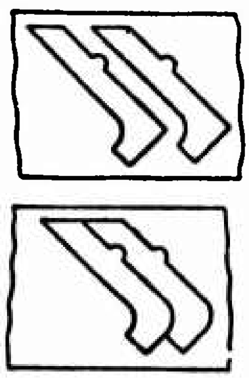
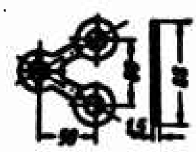
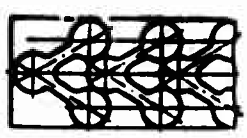
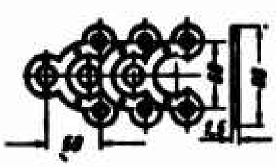
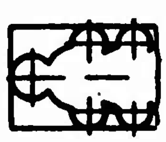
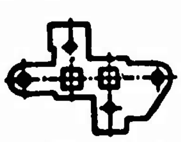
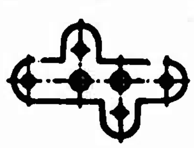
Construction of detail	Diagram of cut	Notes
		$a = c = 0,5\,b$ $a = e = 0,5\,b$ $b = c = d$
		Unsuitable Contour of one side of detail as fas as possible should be a reflection of the other side.
		Unsuitable In construction only official use of detail is foreseen.
		In construction basic elements are preserved along with established dimensions of the part; technologicness is increased.
 Unsuitable		Expenditure on dies is decreased and their stability is increased.

Table 58. (Continued)

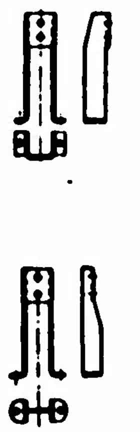
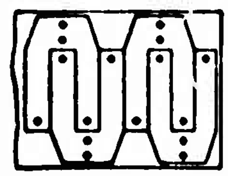
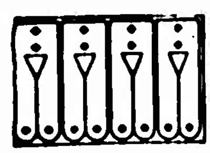
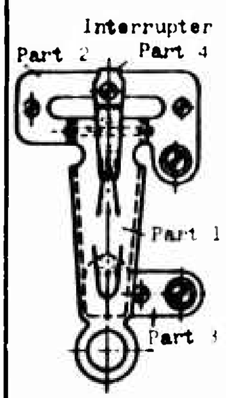
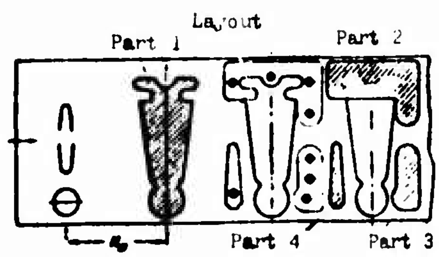
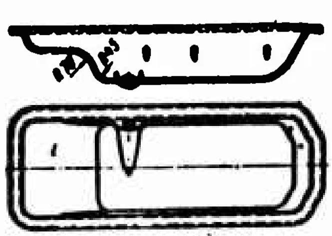
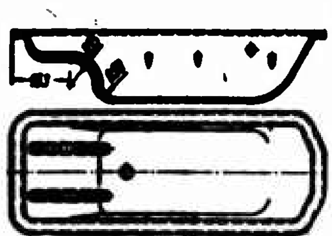
Construction of detail	Diagram of cut	Notes
	 Variant 1  Variant 2	Two variants of constructive shaping of the same detail. For the second variant construction may be done with smaller expenditure of material;
		Configuration of detail is connected completely with cut. Details 2, 3, and 4 are obtained as if from waste of part 1 (scale of general form of interrupt is larger than the scale of the cut).
 a)	 b)	Rib of rigidity and increased radii of linkages introduced in construction b; rejects removed (fold formation in Section 1) in construction a.

Table 59. Examples of Construction of Details and Nodes on Shift of Them to Stamping

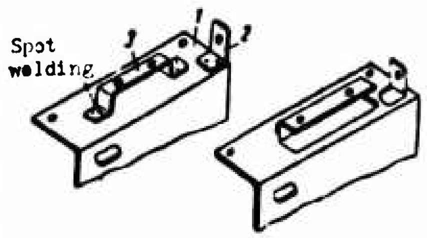
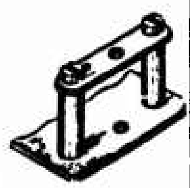
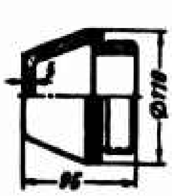
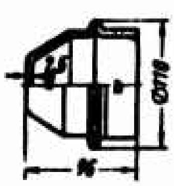
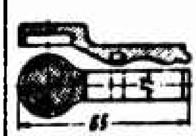
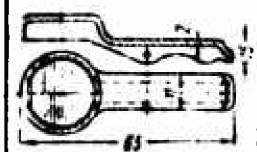
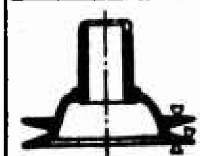
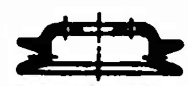
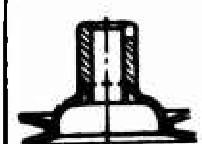
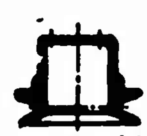
Construction	
Old	New (on shift to stamping)
	
 Milled and riveted catch	Molding for increase of rigidity  Holes under screws for attaching to body
Expenditure of metal and labor consumingness of manufacture are reduced. Instead of three parts 1-3 (welded) the same official assignment is filled by one stamped part.	
	
The same, as in preceding example.	
	
Shift of cast part to stamping lowers weight and labor consumingness.	

Table 59. (Continued)

Construction	
Old	New (on shift to stamping)
	
Shift of hot-stamped part to cold-stamped lowers weight and labor consumingness of manufacture.	
  a - cast constructions of pulley	
	 c - whole stamped construction more perfect than cast and welded.
 b - stampwelded constructions - betten than poured Deficiency - in production difficult to sustain perpendicularity of plane of groove for belt to axis of pulley and identical profile of groove.	Basic advantages: more durable than poured and welded, less labor consuming, ensures identity of dimensions and finishing of constructive forms for economic use of metal.

Establishing of dimensions on a drawing. The technology of sheet stamped parts essentially depends on correctness of establishing of dimensions (Table 60).

Table 60. Examples of establishing Dimensions on Drawings of Stamped Parts

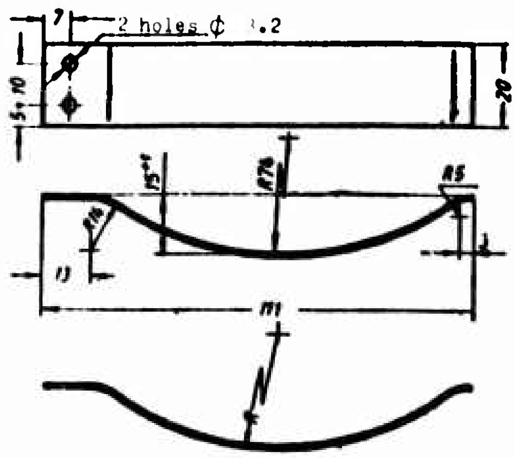
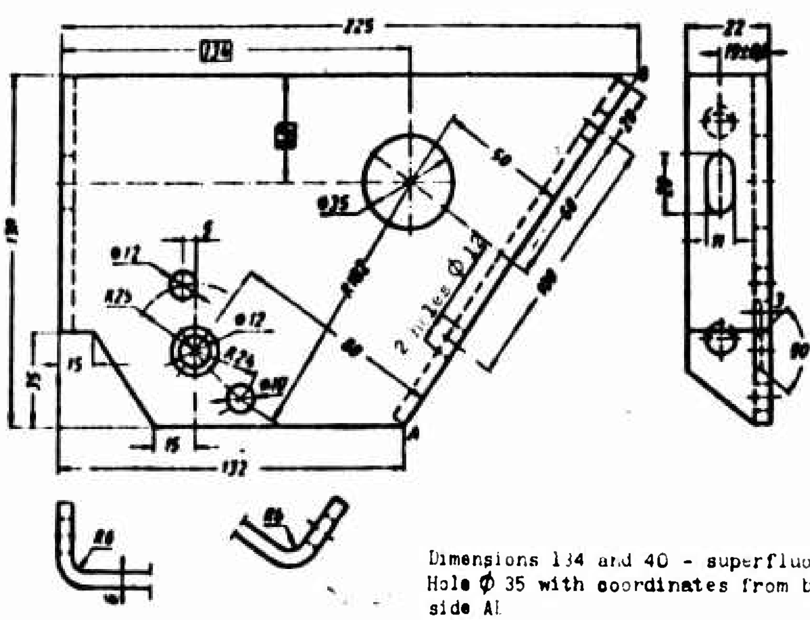
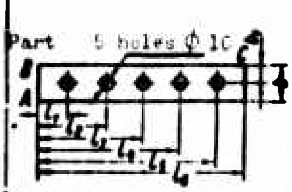
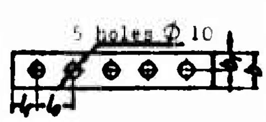
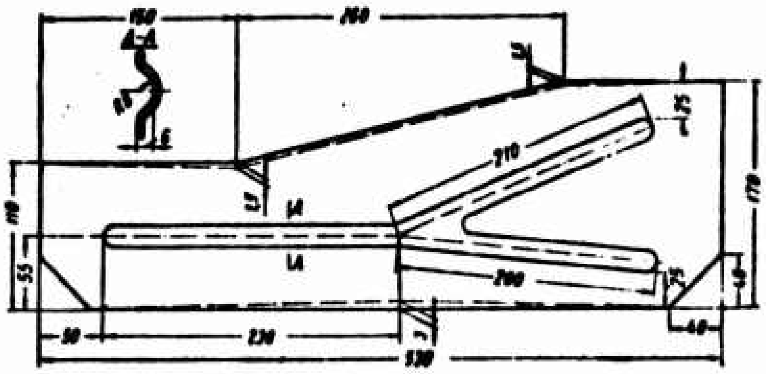
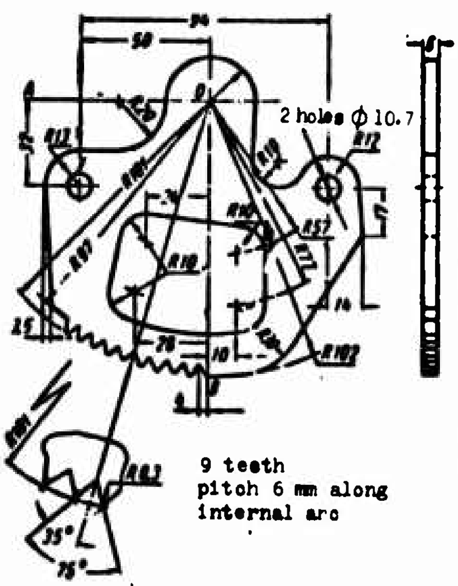
<table>
<tr><td colspan="2">
</td><td colspan="2">Dimension R 74 superfluous, since characteristic dimension for such kind of details is not radius and height. To measure height is easier than radius. During change of height it is easy to correct the operating tool.</td></tr>
<tr><td colspan="2">
</td><td colspan="2">Dimensions 134 and 40 - superfluous. Hole ⌀ 35 with coordinates from base side AB.</td></tr>
<tr><td>
</td><td>Base - external contour (side AB and BC). Small production method of stamping - puncture is produced with adjustable rest.</td><td>
</td><td>Base - internal contour (hole); more productive method of stamping.</td></tr>
</table>

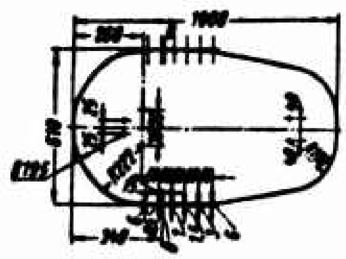
Table 60. (Continued)



By the stroke-dotted lines are designated place of allowed shear drag with indication of dimension of the biggest shear drag.

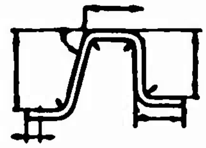
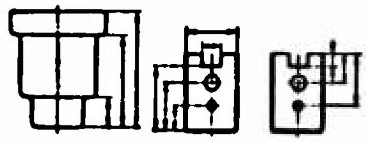
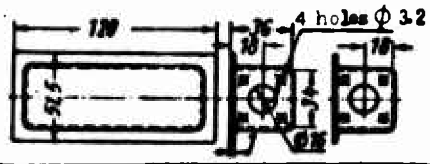
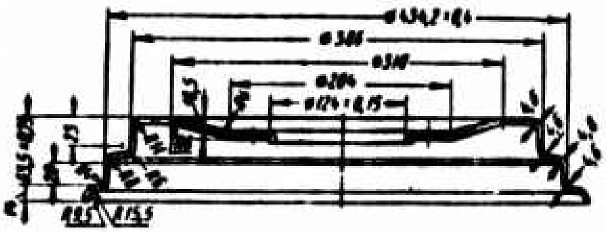


Bases are coordinates - OA and OB. Teeth are shown in increased scale with rounded summits.



Drawing of large dimension flat detail with one axis of symmetry. Second axis 0-0 is selected arbitrarily. From it come the dimensions, as has been shown on the drawing. During manufacture of a die with asymmetric sections measurement is done by patterns which more exactly determine the position of contour of the part.

Table 60. (Continued)

 On drawing of a part dimensions are entered corresponding to dimensions of operating sections of bending die. Radii of bending entered only for internal ones. Dimensions by angles in degrees. On a drawing of a complicated part, prepared by bending it is recommended to give reaming with dimensions, necessary for its construction. On the reamer are not indicated sections of parts obtained by operations after bending.	 Dimensions of details of solids of revolution and box-like form it is possible to enter with respect to internal or external contour, with the exception of radii of rounding (to give only internal). For manufacture of a stamping tool it is preferable to enter internal dimensions of stamped detail. The base for coordination of holes, grooves located on lateral surface, is the bottom or cutoff edge of detail depending upon convenience of fixation. The base for puncture of holes in the bottom are lateral walls of the part
 	As a base for puncture of holes is the flange is taken, but inasmuch as allowance on planeness of flange is not determined it is more correct to take for the base the bottom of the tank.
	In responsible, loaded parts in places, obtaining the biggest thinning, the least thickness s is indicated. In this case 4.6.

On a drawing of a part should be a minimum number of dimensions ensuring its manufacture and check. On drawings of large dimension parts dimensions are entered by coordinates determining the position of the part in space, furthermore, on a drawing reference is made to the main model or mold pattern which is a supplement to the drawing also reproducing the surface of the stamped detail.

In complicated large dimension details dimensions are entered from general coordinate axes of the stamped node. These axes in three planes are base (Fig. 87) axes.

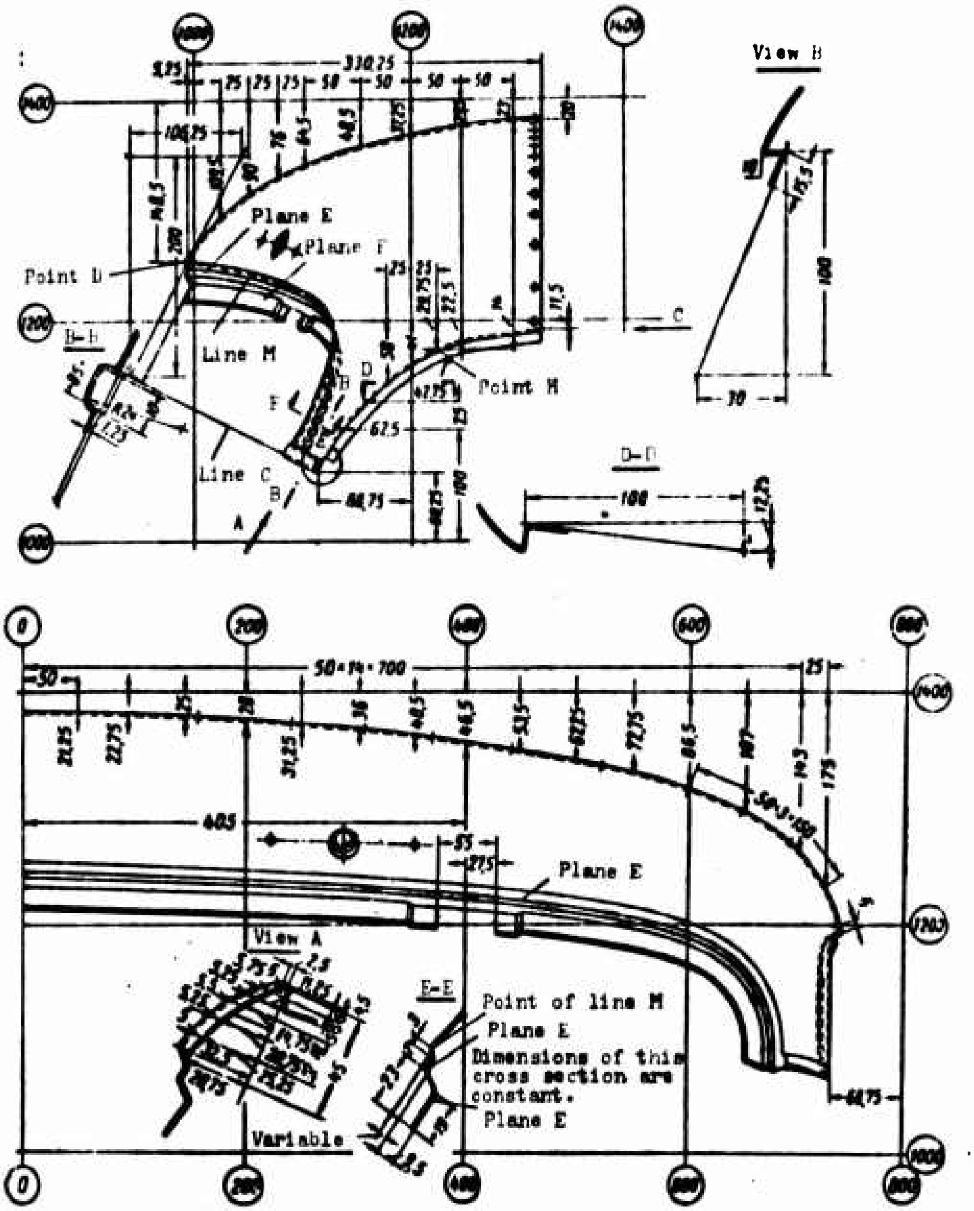


Fig. 87. Dimensioning of large-size parts.

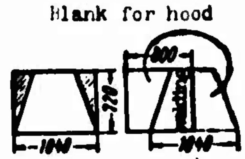
Stamp Welded Constructions of Parts

Application of stamp welded constructions allows making of a part of complicated structural shapes and large dimensions, lowering of weight and increase in rigidity of articles, decrease in labor-consumingness as compared to other technological resolutions of manufacture of the part. The technology of welding allows making of articles consisting of sections obtained by sheet stamping, ductile-stamping, casting from constructional steels of miscellany of brands

with different heat treatment. For construction of stamp welded details selection of materials, dimensions and forms of separate elements are determined by requirements of rational stamping and welding technology (Table 61).

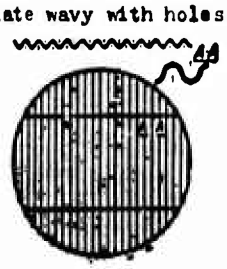
Table 61. Stamp Welded Constructions

Blank for hood



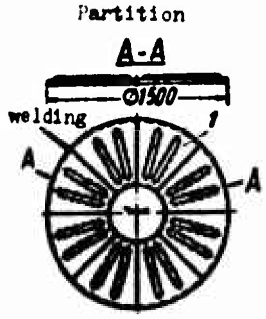
a - homogenous, shaded sections - waste; b - welded, without waste

Plate wavy with holes



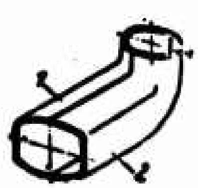
Prepared by welding from three parts, puncture of holes and bending

Partition



Prepared by stamping of sectors and subsequent welding

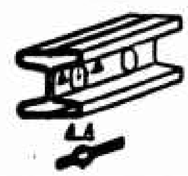
Branch pipe



Welded construction from two stamped elements 1 and 2

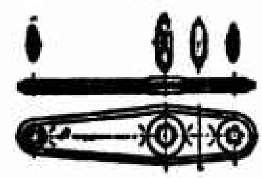
Table 61. (Continued)

Beam



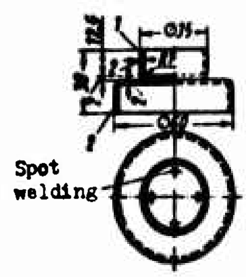
Bending is done with subsequent welding of two elements

Lever



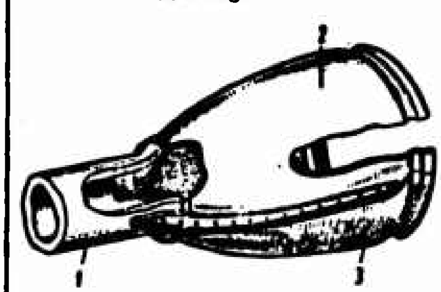
Arm prepared from two stamped elements, united by point or seam welding

Cover



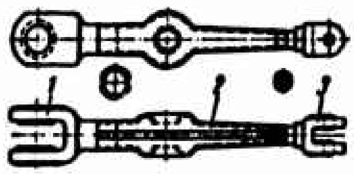
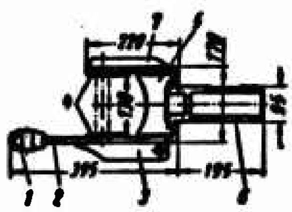
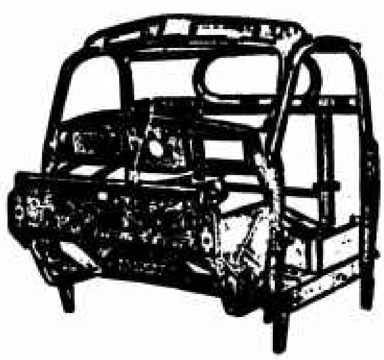
Elements 1 and 2 are prepared by drawing and are united by spot welding

Loading node



Stamped details 2 and 3 are united along the flange by spot welding; pipe 1 is disassembled and is welded to parts 2 and 3

Table 61. (Continued)

Rocker arm  Elements 1 and 3 are prepared by volume stamping; element 2 - sheet stamping; united by welding. Light construction
Bracket of beam  Consists of seven elements; 1 and 6 - Volume 2, 3, 4, 5, 7 - sheet stamping; united by electric arc welding. Lightness of construction
Cabin of truck  Interchangeability of stamped parts allows assembly of them from conveyer with application of welding machines.

Stamping by Explosion

Stamping by explosion is applied in small-serial and individual production for manufacture of parts of any shape and dimensions from carbon and alloy steels. Stamping by explosion has special value during manufacture of details from hard-to-work metals.

As an energy source launching and high explosive materials [EM] (BB) are used.

During work with launching EM usually closed equipment is used which promotes increase of impulse of stamping. For work with high EM developing very high pressure of explosion, open equipment is used. For explosion of EM in air the medium of the blank is subjected to a series of impulses with pulse duration in milliseconds. According to certain data the efficiency of an explosion is air constitutes 4%, and in water 33%. Varieties of stamping by explosion are application of detonating gas (oxygen — hydrogen with ratio 8:1) and electro-hydraulic method. The last two methods at present have small application in spite of a number of advantages as compared to EM. Use of detonating gas is the

most effective for stamping of details of large dimensions. The electro-hydraulic method ensures more exact control, large safety and higher quality of stamping at the expense of application of multiple electroimpulses.

The force necessary for stamping is determined (Fig. 88) by selection of corresponding EM, its dosage, geometric form of charge, distance and location of charge with respect to blank, selection of medium transmitting the force.

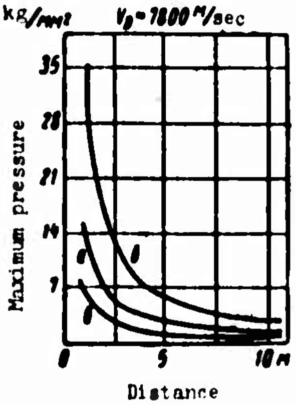


Fig. 88. Graph of maximum pressures during stamping by explosion. Explosion under water v = 7800 m/sec; weight of charge: a) 0.45 kg; b) 4.5 kg; c) 0.045 kg.

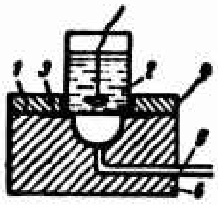


Fig. 89. Stamping by explosion of concentrated EM: 1 – blank; 2 – water; 3 – detail; 4 – clamp; 5 – vacuum channel; 6 – die.

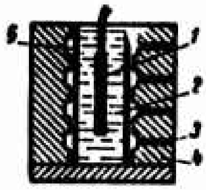


Fig. 90. Stamping by explosion of cylindrical EM: 1 – charge; 2 – water; 3 – vacuum channel; 4 – die; 5 – blank.

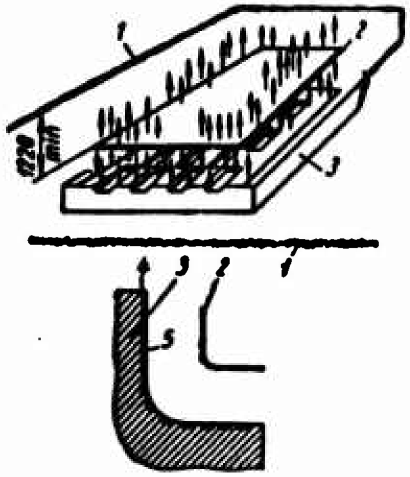


Fig. 91. Stamping by explosion of petal EM: 1 – water level; 2 – charge; 3 – die; 4 – blank; 5 – article.

The most frequent stamping by explosion is used for operations of molding and sizing of sheet and tube parts in thickness to 25 mm and with a diameter of several meters. Accuracy of stamping by explosion reaches tenths and even hundredths of a millimeter (±0.25-±0.02 mm).

For carrying out of explosions of EM three types of charges are used:

1) concentrated – for tubes and cylindrical blanks (Fig. 89);
2) cylindrical – for tubes and cylindrical blanks (Fig. 90);

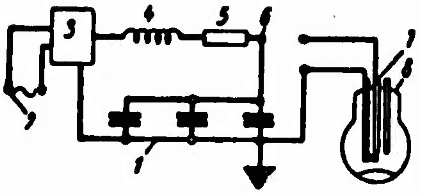


Fig. 92. Diagram of electro-hydraulic method of stamping; 1 – battery of capacitors; 2 – feed of alternating current; 3 – source of energy of high tension; 4 – high-frequency throttle; 5 – resistance; 6 – element commutator; 7 – coaxial electrode; 8 – article.

3) petal – for details of small curvature, crimping sheets and complicated construction forms (Fig. 91).

In Fig. 92 is presented a diagram of electro-hydraulic stamping.

Assembly by Cold Stamping

Assembly using cold stamping is used for guarantee of nondetacheable joinings (Table 62).

Table 62. Examples of Nondetachable Joinings Done by Cold Stamping

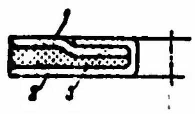
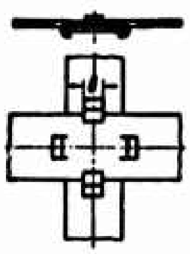
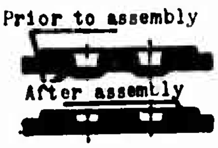
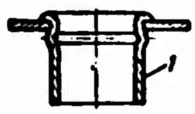
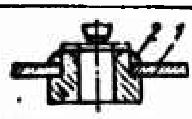
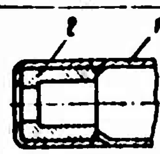
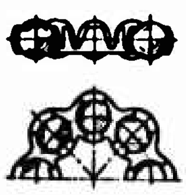
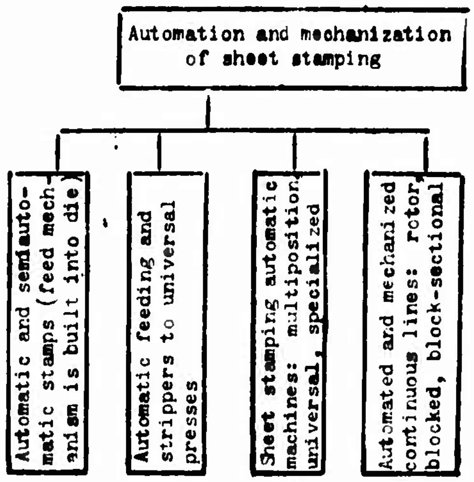
Combinable details	Diagram of joining (assembly)	Method of joining	Note
Sheet stamped		Folding lock	Used for metal of thickness to 2 mm
		The same	Assembly of three details - 1, 2 - metallic; 3 - nonmetallic
		Joining by bracket	Used for metal of thickness more than 2 mm
		Parts are connected by means of cut and fold of lugs	Used for metal of thickness to 3 mm
		Joining of sheet-stamped hemispheres by pressing	–

Table 62. (Continued)

Combinable details	Diagram of joining (assembly)	Method of joining	Note
Sheet stamped		Rivet joining at the expense of body of one of parts	Used for thin-sheet metal
		Joining by rivet, obtained at the expense of body of one of parts	During joining possible only during observance of shown relationships. Used for $s \geq 4$ mm
Sheet stamped with parts prepared by other methods		Joining at the expense of deformation of tubular blank	Detail 1 - ready tube is obtained by drawing. Such joining may be with several plates
		Riveting with a clinching iron	Detail 1 stamped, Detail 2 is prepared on metal-cutting machines
		Notch and fold of lugs	Detail 1 stamped, Detail 2 mechanically treated
		Assembly of balls in separator	-
		Framing of ball with use of clinching iron	

Automation and Mechanization of Sheet Stamping

Methods of automation and mechanization are shown in the diagram.



In sheet stamping production presses are used: with lower drive, multiposition, and also interlocked universal presses and specialized equipment. A press-automatic machine with lower drive is used for stamping of small parts. Multiposition presses are applied usually in specialized production for stamping of small and average details, manufacture of which requires several operations. These presses are high production presses. However their universality is very limited.

A rotary continuous line allows complex automation of different technological processes of light stamping, thermal control and other operations. It consists of operating and transport rotors.

Universal presses interlocked in automatic lines allow wide changes in technology and form of finished production. Therefore they possess large flexibility as compared to multiposition automatic machines.

Resolution of the question of automation and mechanization of stamping is determined, as and in all branches of machine building, by economic expediency, easing of labor and guarantee of safety of work (Table 62a and Fig. 93).

Table 62a. Some Data on Productivity of Presses and Lowering of Labor-Consumingness on Introduction of Machines

Means of mechanization and automation	Increase of productivity of press	Lowering of labor-consumingness
Mechanical hand for supply and yield of small piece blanks...	By 3 times	By 3 times
Magazine with damper supply...	The same	The same
Installation for automatic feeding of bands..............	By 1.5 times	"
Roll and roller supply........	The same	"
Hook and tongs supply.........	"	"
Sheet stacker.................	By 1.5 times	By 2 times
Mechanical hand for yield of big parts.....................	–	The same
Device for automated supply and yield of large dimension parts.......................	By 1.5 times	By 6 times

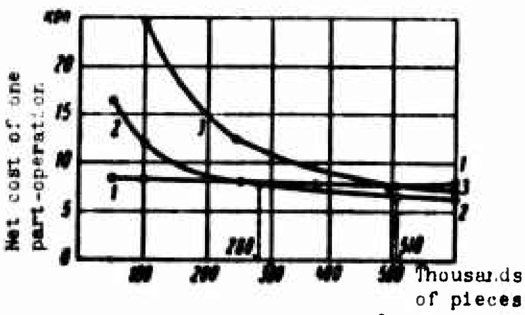


Fig. 93. Graph of dependence of primecost of detail on size of lot and degree of automation: 1 – manual work; 2 – with application of machines; 3 – automated production.

COLD UPSETTING. COLD VOLUME STAMPING

During cold embossing an article can be made with precision of 2-3-rd classes and cleanness of surface, corresponding to 6-10th classes; as compared to treatment in hot state expenditure of metal on projecting edge and cinder drops; there is no necessity to consider shrinkage, it is possible to prepare very small parts which in the hot state are difficult to stamp or it is impossible.

On cold-heading presses-automatic machines it is possible to carry out processes of upsetting, cold volume stamping in direction of axis of blank, reduction (pressing) or rod and pressing by method of effusion by means of pushing through eyelet, cutting of upset part of blank along required contour, pressing of deepenings in head and

rod and so forth.

By the method of cold volume stamping and upsetting, not only support parts (nails, bolts, screws, rivet, nut), but also machine parts and instruments more complicated in technological relation are made, for instance, step pins, wheel pins and spherical pins of steering control of automobile, rollers and balls of roller bearings and others (Fig. 94) [39].

Group	Sub-group	Characteristic of sub-groups of articles	Types of articles and their approximate configuration
I Rod articles with thickening	1	In the form of solids of revolution with symmetrical head on end of rod	
	2	With heads and subheads of non-curved section on end of rod	
	3	With asymmetric heads	
	4	With depression in heads	
	5	With flanges on head	
	6	With one or several thickenings not on end of rod	
	7	With bilateral thickening on ends of rod	
	8	With rod, subjected to transverse deformation	
	9	With two rods	
	10	With unthrough recession in rod	
Unrod articles II	11	Solid	
	12	Type of caps, rings and nuts	

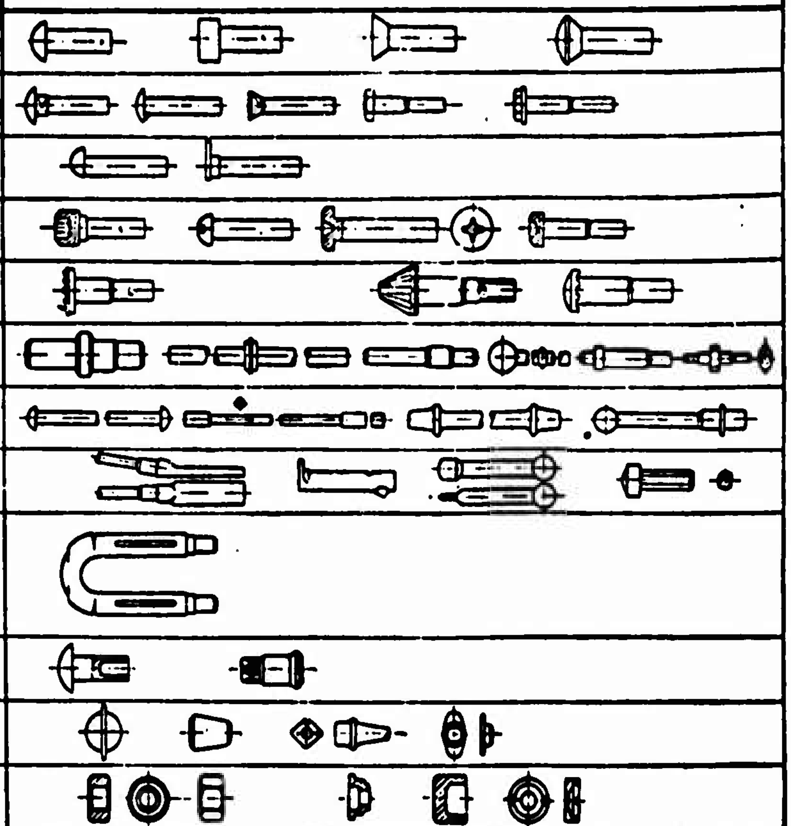


Fig. 94. Examples of details, prepared by the method of cold upsetting and volume stamping.

The biggest rod diameter of steel parts, prepared by the method of cold upsetting, constitutes 32 mm. Maximum length of details, stamped on standard cold-upset presses-automatic machines, does not exceed 200 mm, on special presses-automatic machines it is possible

to upset a part of length to 400 mm; with semiautomatic and automatic stamping of previously cut blanks it is possible to produce upsetting of heads, reduction and rolling of threads for parts in length to 1800 mm.

The process of cold extrusion is based on the use of plastic properties of metals and alloys also constitutes a form change of the blank by means of manifold compression of metal with effusion of its outside into the open cavity of the die.

Perfumery small tubes, body of poles for pocket batteries, body of electrical capacitors, screens for radio tubes, sockets, capacitors, shells for electrical heating instruments, tubes for water cooling of filters of desalters, valves and many other articles are produced by cold extrusion.

Metal, Used for Upsetting, Volume Stamping and Pressing in the Cold State

Cold upsetting is done from sized metal of chiefly round section 0.6-38 mm in diameter with allowed deflections for normal accuracy of manufactuer of the 4th class (system of shaft) and for heightened accuracy — class 3a. In separate cases it is possible to use material of large diameter and not only round, but right-angle, hexahedral, trapezoidal and oval profile.

Chiefly used is steel of carbon qualitative brands from 0.8 by 45; alloy steel brands 15G, 20G, 35G2, 15Kh, 20Kh, 30Kh, 35Kh, 40Kh, 40KhN, 15KhF, 20KhF, 25KhNVA, 40KhFA, 40KhNM, 30KhNM, 30KhGS, 18KhN3A, ShKh9, ShKh15, 1Kh18N9T, U10A, U12A and others.

Carbon and alloy steel intended for cold upsetting, should have hardness not more than NV207.

Temporary resistance to fracture not more than 75 kg/cm^2, relative narrowing of not less than 40% and elongation per unit

length δ_5 not less than 13%.

Physico-mechanical properties and chemical composition of steel sized wire for cold upsettings are given in All-Union Government Standard 5663-51 and 1051-59. Steel used for cold upsetting, has to possess high plasticity and small ability for hardening.

The influence of chemical composition on the properties of steel are given in Table 63.

Table 63. Influence of Chemical Composition on Plastic Properties of Steel Subjected to Cold Upsetting

Chemical element	Improves	Worsens	Additional explanations
Carbon (C)		+	Increase in content of C by 0.1% increases σ_B by 6-8 kg/mm^2. Cold upsetting of carbon steel with allowance C > 0.2% requires annealing it on structure possessing the greatest plasticity, — granular perlite
Silicon (Si)		+	The most negative value for cold upsetting is the presence of Si in steel with content of carbon from 0.45 to 0.5%. The content of Si > > 0.2% sharply lowers plasticity, evokes during deformation significant heating of metal, decreases stability of dies and requires application of large efforts for upsetting
Manganese (Mn)		+	In carbon steel the content of Mn does not have to exceed 0.65%. The presence of Mn is necessary for decrease of harmful influence of sulfur S
Chromium (Cr)		+	Cr especially lowers the plastic properties of high-carbon steel. Increase of content of Cr by 0.1% in steel 40 increases σ_B by 2.5 kg/mm^2. On lowering of plasticity for a content of carbon in steel less than 0.3%, the influence of Cr proves small

Table 63. (Continued)

Chemical element	Improves	Worsens	Additional explanations
Tungsten (W)	+		Admixture W in quantity 0.15-0.25% improves process of cold upsetting with simultaneous increase in σ_T and σ_B
Molybdenum (MO) Vanadium (V)	+ +		Improves process of cold upsetting and increases σ_T and σ_B
Aluminum (Al)	+		Steel with addition of Al as deoxidizing agent (0.03-0.05%) possesses high plastic properties and is inclined to formation of granular perlite
Nickel (Ni)	+		Improves plasticity of steel

The surface of sized material should be smooth, without cracks and seams, lap, stratifications, black marks and rust.

Steel, intended for cold upsetting is supplied in annealed or normalized state, mordanted by weak solution of acid and neutralized in lime milk, and also with parkerized surface.

Besides steel nonferrous metals and alloys are used widely: pure aluminum (brand A00 AVI and AV2) and certain aluminum alloys of type duralumin (brand D3P, D1, D16), zinc (brand Ts0, Ts1 and Ts2), copper (brand M1, M2 and M3), copper-zinc alloys of type of brasses (LS59, L62 and L68), monelmetal and others.

Methods of Embossing of Heads

Upsetting support parts id done chiefly on horizontal cold-upset presses-automatic machines. Embossing of heads can be carried out in a die, punch and simultaneously in both parts of the die (Fig. 95a-1). Speed of punch in beginning of upsetting of blank is equal to 0.15-1.5 m/sec. Speed of deformation along the axis of the blank $v_z = \frac{\varepsilon}{t} \cdot 100$

constitutes 1300-20,000% sec (Table 64), where ε is the degree of deformation on upsetting (upsetting); t is the time of period of deformation in sec.

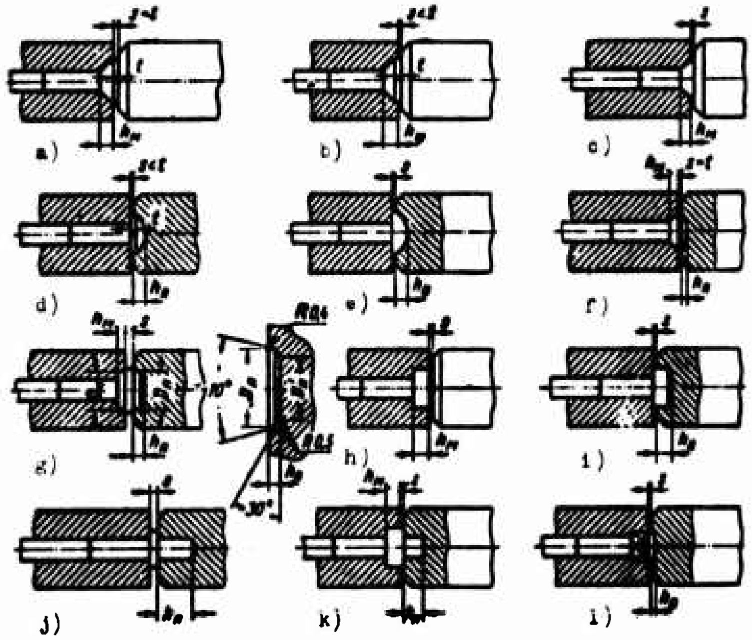


Fig. 95. Methods of embossing of heads.

Table 64. Speeds of Punch in Beginning of Deformation and Speed of Deformation

Press-automatic machines		Range of dimensions of automatic machines in mm	Assumed value of $\frac{h_0}{d}$	Angle of position of crank in beginning of stamping in degrees	Speed of punch v_{pos} in m/sec	Speed of deformation v_z in %/sec
Single-stroke cold-upsetting	With whole die	3—10	2	—	0,25—0,4	4950—1800
	With split die	4,5—6			0,7—0,8	9000—6000
Two-shock cold-upsetting	With whole die	3—20	3	42—45	0,7—1	6000—1200
	With split die	6—25			0,75—1,3	6800—1200
	With universal die	6—20			1,25—1,4	7800—2200
Nail-making	With horizontal location Clamp and detachable matrices	1,2—4,5	1,5	20	0,5—0,9	20 000—12 000
Cut with possibility of use for repeated stamping	With crank drive of slider	10—20	—	40	0,5—0,65	—
Nut stamping	Multiposition	6—30	—	20	0,14	—

Selection of quantity of transitions and calculation of conical (preparing) punches. Cold upsetting is carried out:

1) in a die (monoposition upsetting) for one blow (Fig. 96a and b) or by the diagram of the consecutive process (Fig. 96c and d) for two or three blows;

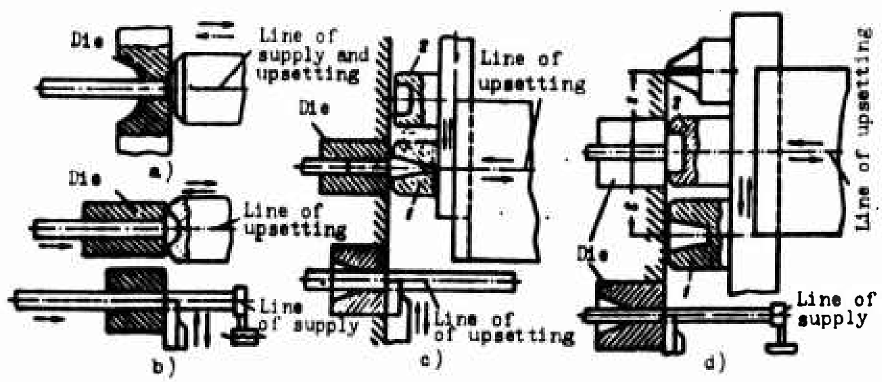


Fig. 96. Diagram of monoposition upsetting for two and three blows of consecutive action: a, b) single-stroke upsetting of heads of nail and rivet; c, d) two- and three- shock upsetting; 1 and 2 — punches.

2) in several dies (Fig. 97) by the diagram in a parallel-consecutive process (multiposition upsetting).

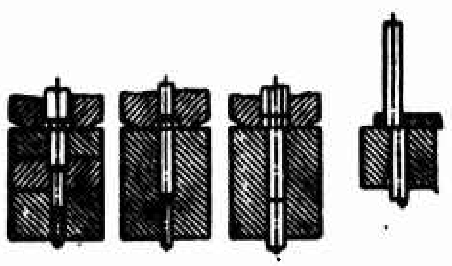


Fig. 97. Diagram of process of multiposition upsetting in parallel-consecutive action.

For monoposition cold upsetting embossing of an article is carried out for 1, 2 and 3 transitions depending upon its configuration and dimensions (Table 65). The biggest quantity of type dimensions of support parts embraces two-shock upsetting.

Table 65. Selection of Quantity of Transitions for Upsetting of Rod Support Parts

Number of transitions (blows)	Relative dimensions of upset part of blank and upset head		No. Fig.	Details
	$\frac{h_0}{d}$	$\frac{D}{d}$		
1	2.5	2.0	98	Rivets, screws, woodscrews and similar articles with semicircular, countersunk or semi-countersunk head
2	2.5–4	2–2.5	99	Blanks of bolts, rivets, screws and other articles, having cylindrical head, heads with dogs ears or square subheads
3	4–6	2.5–4	–	Screws with cross-like slits, bolts with external and internal hexahedron and other complicated technologically parts

NOTE: 1. Conical (preparing) punch 2 (Fig. 99a and 96c), intermediate in case of three blow upsetting (Fig. 96d) and finishing 3 (Fig. 99b) automatically establish on line of upsetting consecutively before corresponding blow.

2. Punches 2 and 3 (Fig. 99; see also Fig. 96c and d) are secured in punch carriage, which shift in upsetting slider vertically or (rectilinearly) along the arc.

Multiposition upsetting is carried out by the following diagram: blank after every transition is transferred from one die to another and to it at every position comes the appropriate punch.

For manufacture of short hexahedral bolts and other similar articles also multitransition upsetting is applied. In this case the blank remains during all the process of embossing in the same die; the block of dies with blanks on transitions periodically turns, and punches shift along the same lines of upsetting.

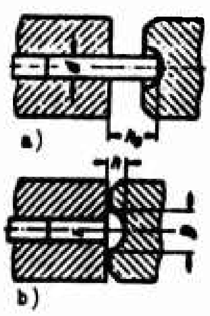


Fig. 98. Diagram of upsetting in one transition; a) beginning of upsetting; b) end of upsetting.

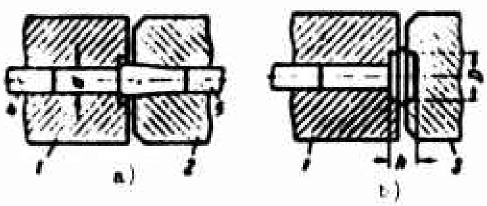


Fig. 99. Diagram of upsetting in two transitions: a) end of first transition; b) end of second transition; 1 – die; 2 – preparing punch; 3 – finishing punch; 4 – ejector; 5 – support cam.

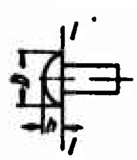
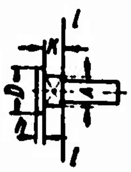
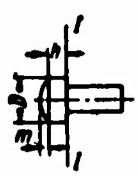
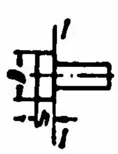
The dies for multiposition upsetting are executed with preparing and final passes, but during multitransition, only with final passes, (as for monoposition upsetting). For all methods or upsetting and volume stamping in accordance with the assumed technological processes preparing, preliminary, final and other punches are used.

For determination of free length, and also for calculation of dimensions of the operating cavity of a conical punch that section of the rod of an article at the place of transition of it into the head lies in plane I-I (Table 66), which is called basic. The thickened part of the rod, diameters of which do not exceed 1.3 the diameter of the initial blank (for non-curved section correspondingly is taken the same increase of large dimension of the section), belongs to the rod, but the thicker part is taken for the head. For determination of free length the weight of the metal, going into formation of the head and filling of gaps of the channel of the die from the basic plane to the butt part of the blank on the side of the rod is considered.

For development of technology of cold upsetting of a newly mastered part it is necessary experimentally to check the selected number of transitions. Specially complicated in technological relation parts are parpared for four and even for five transitions. Sometimes, especially for upsetting of complicated articles of steel, containing carbon more than 0.2%, intermediate annealing is required. In this case repeated upsetting on presses with a bunker load is used which

significantly expands the nomenclature of upset parts both with respect to their configuration, and dimensions.

Table 66. Formulas for Determination of Diameter of Major Base of Frustum of a Cone (D_K) of a Preparing (Conical) Punch (Without Calculation of Volume)

Sketch	Formula
	$D_K = \sqrt[3]{6\,\mathrm{tg}\,\frac{\alpha}{2}\,D^2h + d_K^3} - 2\,\mathrm{tg}\,\frac{\alpha}{2}\,n$ $D_{K_1} = \sqrt[3]{0{,}314\,D^2h + d_K^3} - 0{,}1n$ $D_{K_2} = \sqrt[3]{0{,}63D^2h + d_K^3} - 0{,}2n$
 $1{,}1A > D_K'$ $A > 1{,}1d_H$ $A > 1{,}4d_H$	$D_K = \sqrt[3]{6\,\mathrm{tg}\,\frac{\alpha}{2}\,D^2h + 0{,}4A^2K + d_K^3} - 2\,\mathrm{tg}\,\frac{\alpha}{2}\,n$ $D_{K_1} = \sqrt[3]{0{,}314D^2h + 0{,}4A^2K + d_K^3} - 0{,}1n$ $D_{K_2} = \sqrt[3]{0{,}63D^2h + 0{,}4A^2K + d_K^3} - 0{,}2n$
	$D_K = \sqrt[3]{6\,\mathrm{tg}\,\frac{\alpha}{2}\left(D^2h + \frac{D^2m}{2} + \frac{2m^3}{3}\right) + d_K^3} - 2\,\mathrm{tg}\,\frac{\alpha}{2}\,n$ $D_{K_1} = \sqrt[3]{0{,}314\left(D^2h + \frac{D^2m}{2} + \frac{2m^3}{3}\right) + d_K^3} - 0{,}1n$ $D_{K_2} = \sqrt[3]{0{,}63\left(D^2h + \frac{D^2m}{2} + \frac{2m^3}{3}\right) + d_K^3} - 0{,}2n$
	$D_K = \sqrt[3]{6\,\mathrm{tg}\,\frac{\alpha}{2}\left(\frac{D^2h}{2} + \frac{2h^3}{3}\right) + d_K^3} - 2\,\mathrm{tg}\,\frac{\alpha}{2}\,n$ $D_{K_1} = \sqrt[3]{0{,}314\left(\frac{D^2h}{2} + \frac{2h^3}{3}\right) + d_K^3} - 0{,}1n$
 $D_1 > D_K'$ $D_1 > 1{,}3d_H$ $D_1 > 1{,}5d$	$D_K = \sqrt[3]{6\,\mathrm{tg}\,\frac{\alpha}{2}\left(\frac{D^2h}{2} + \frac{2h^3}{3} + D_1^2K\right) + d_K^3} - 2\,\mathrm{tg}\,\frac{\alpha}{2}\,n$ $D_{K_1} = \sqrt[3]{0{,}314\left(\frac{D^2h}{2} + \frac{2h^3}{3} + D_1^2K\right) + d_K^3} - 0{,}1n$ $D_{K_2} = \sqrt[3]{0{,}63\left(\frac{D^2h}{2} + \frac{2h^3}{3} + D_1^2K\right) + d_K^3} - 0{,}2n$
 $1{,}1A > D_K'$ $A > 1{,}1d_H$ $A > 1{,}4d_H$	$D_K = \sqrt[3]{6\,\mathrm{tg}\,\frac{\alpha}{2}\left(\frac{D^2h}{2} + \frac{2h^3}{3}\right) + 0{,}4A^2K + d_K^3} - 2\,\mathrm{tg}\,\frac{\alpha}{2}\,n$ $D_{K_1} = \sqrt[3]{0{,}314\left(\frac{D^2h}{2} + \frac{2h^3}{3}\right) + 0{,}4A^2K + d_K^3} - 0{,}1n$ $D_{K_2} = \sqrt[3]{0{,}63\left(\frac{D^2h}{2} + \frac{2h^3}{3}\right) + 0{,}4A^2K + d_K^3} - 0{,}2n$

For a set of metal — decrease of relative length of upset part of blank and increase of average diameter — preparing (conical) punches are used, the operating cavity of which should satisfy two basic requirements:

displacement of axis of blank should be not more than 0.15 its diameter (Fig. 100); relative length of conical upsetting $\psi_1 = \frac{h}{d_{cp}}$ (Fig. 101) not more than 2.5 [34].

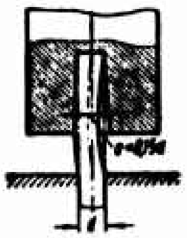


Fig. 100.

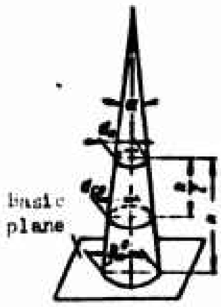


Fig. 101.

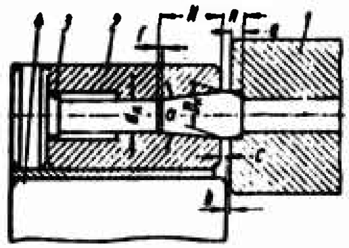


Fig. 102.

Fig. 100. Beginning of upsetting by conical punch and permissible bend of blank.

Fig. 101. Calculated bone.

Fig. 102. Position of upsetting tool during final stage of upsetting by the preparing conical punch: I-I — base plane; 1 — die; 2 — conical punch; 3 — support cam; 4 — finishing punch.

Observing these conditions, oppositely affecting the size of angle of the cone of the punch, proceeding from volume of metal going into formation of the head the diameter of the calculated cone D_K^0 is found (see Fig. 101) by the formula

$$D_K^0 = d_n \sqrt[3]{6\,\mathrm{tg}\frac{\alpha}{2}\cdot\frac{l}{d_n}+1}.$$

During calculation of dimensions of conical cavity non-gain n of the punch to the basic plane [4] is considered.

The diameter of the cone D_K (Fig. 102) is determined by the formula

$$D_\kappa = \sqrt[3]{\frac{24}{\pi}\,\mathrm{tg}\frac{\alpha}{2}V + d_\kappa^3} - \mathrm{tg}\frac{\alpha}{2}n,$$

here d_K is the diameter of the cylindrical hole of the conical punch, or least diameter of the blank ($d_{0\ min}$); V — volume of deformed part of blank going into formation of the head; n — non-gain of the conical punch to the basic plane;

$$n = a + b + c,$$

where a — distance from front face of die to basic plane; b — distance between front face of final punch and die; c — distance between front face of conical and final punches.

For standard support articles the optimum angle of cone for first conical upsetting is 6° (3° to the side), and for the second — 12°. Punches with such angles of cone ensure conical upsetting of head, for which $\psi_1 = \frac{h_0}{d_{cp}} = 1.5\text{-}2.5$.

For angles of 6° and 12°, the diameters of the cones corresponding to D_{K_1} and D_{K_2} are determined by the simplified formulas:

$$\text{for } \alpha = 6^\circ \quad D_{\kappa 1} = \sqrt[3]{0{,}4V + d_\kappa^3} - 0{,}1n;$$
$$\text{for } \alpha = 12^\circ \quad D_{\kappa 2} = \sqrt[3]{0{,}8V + d_\kappa^3} - 0{,}2n.$$

Height of operating cavity of punch is found by the formula

$$H = \frac{1}{2}\,\mathrm{ctg}\left(\frac{\alpha}{2} - \delta\right)\cdot\left(D_\kappa - d_\kappa\right),$$

where δ is half of the allowance on angle α of the cone.

During manufacture of the cone of a punch at a nominal angle will be formed a section f (see Fig. 102), which ensures the best centering of the blank.

Formulas for determination of height of the operating cavity of first and second punches are assigned the following forms:

$$H_1 = 10(D_{к1} - d_к)$$

and

$$H_2 = 4{,}8(D_{к2} - d_к).$$

Formulas for determination of $D_к$, $D_{к_1}$ and $D_{к_2}$ without calculation of volumes are given in Table 66.

Selection of type of matrices. Type of die for upsetting is determined by relative length of rod of upset part, technology of upsetting and requirementsof quality (Table 67).

Upsetting in a whole die (Fig. 103). A wire or rod 1 is supplied periodically to revolving grooved rollers 2 through the hole of a detachable die 3 to stop 4. During movement of knife 5 forward from the rod will be cut a blank, which with the help of a special holding device 6 is transfered to the line of upsetting. During movement of punch 7 to die 8 the blank at first is pushed into the hole of the die to the stop at the ejector rod 9, and then occurs upsetting of head. The blade after the blank has entered somewhat into the pass of the die goes back to its initial position. With departure of the punch, the upset part is removed from the die by the ejector 9. The length of rod of the stamped detail is determined by the position of the ejector 9.

Upsetting in a split die (Fig. 104). The wire or rod 1 moves periodically with revolving grooved rollers 2 through the detachable die 3 and opened dies 4 and 5 to the turning stop 6. The die 4, moving to the right, using its own butt surface will cut from the rod a blank, which is transferred by the dies 4 and 5 to the line of upsetting where it is pressed.

The protruding part of the blank is upset by the punch in the head of corresponding shape.

Table 67. Selection of Type of Die for Cold Upsetting

Type of die	Length of rod of upset detail	Assignment of die	Quality of article	Technological peculiarities
Whole	$l \leq 8d$	1. Stamping and upsetting of detail 2. Reduction of rod (in this case the die consists of the die itself and an eyelet)	Detail is obtained smooth without burrs under the head	Maximum length l of part upset in a whole die is determined by the force of ejection and durability of ejector. In individual cases a length $l \leq$ ≤ 10 d is allowed; the pass of the die executed with a small cone for easing of ejection
Split	$l > 8d$	1. Stamping and upsetting of detail 2. Flattening, pressing of deepenings and so forth 3. Bending of rod 4. Clamp of blank during upsetting of long rods for retention from longitudinal displacement	Under the head and along the length of the rod in places of disassembling of the die can be formed small burrs	Reduction of rod into a split die is not produced. In special presses-automatic machines with a split die it is possible to carry out upsetting of heads for long pulls (to 1800 mm) or reduction by punch of ends of them by a thread. Dies in this case are made with transverse grooves in passes. It is possible to produce also simultaneously bilateral upsetting on special presses-automatic machines
Universal (in matrix pad can be inserted both a whole and a split die		1. Stamping and upsetting of detail 2. Reduction of rod (in case of upsetting in a whole die)	Quality of detail is determined by type of die, inserted in matrix pad	During upsetting, split dies are compressed. For easing of knockout one die departs from the other. Section and transfer of blank are carried out as in presses — automatic machines with a whole die; in this case the split dies are not used for transverse deformation.

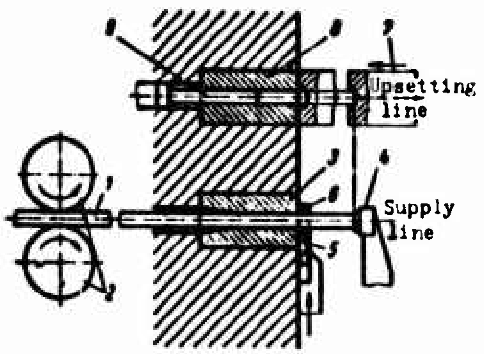


Fig. 103. Process of upsetting in a split die.

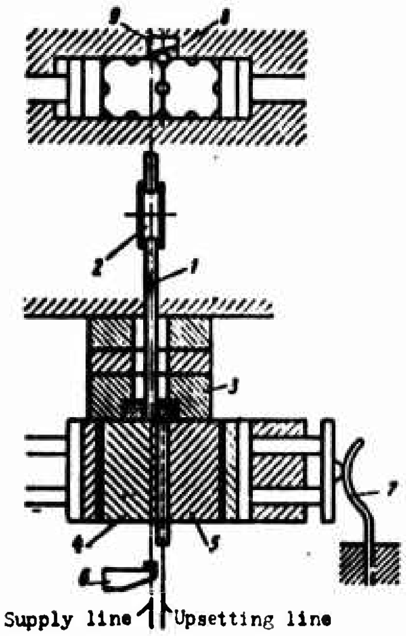


Fig. 104. Process of upsetting in a split die.

In the process of upsetting the diameter of the cut blank increases somewhat and the die is separated by an amount δ, equal to 0.1-0.2 mm. The dies are built taking into account that the rod of the upset article will have a round section.

After upsetting the die 4 and 5 with the help of a squeezing spring 7 are displaced back to the line of supply; during reverse motion the dies are opened by an amount Δ by roller 8 lowered by means of a leveled plank 9 (or wedge). The upset detail is ejected during the following cycle of supply. The length of the upset detail is determined by the length of the actual die.

Split dies are executed most frequently with square sections; also hexahedral and sometimes octahedral dies are used.

Upsetting in universal (combined dies). Universal dies are whole dies divided into two halves, and upsetting in them occurs by the same principle as in a whole die; at the moment of ejection compression of the two halves of the die is weakened.

Methods of Manufacture of Bolts with Hexahedral Head on Presses-Automatic Machines

1. Monoposition stamping (Fig. 105):

a) Upsetting on two-blow press-automatic machines of a hexahedral head (method ZIL (ЗИЛ)) with formation in it of a cylindrical groove of depth to 0.5 the height of the head. The depicted deepening, without worsening the quality of the article, ensures the best filling of the hexahedral cavity of the die [12]. The advantage of this method is the possibility of wasteless upsetting of bolts on usual two-shock press-automatic machines; deficiency — illegible filling of edges.

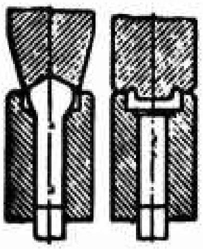


Fig. 105. Diagram of obtaining of a hexahedral head by the ZIL method on a two-blow automatic machine.

b) Upsetting on a usual two-blow cold-upsetting automatic machine with application of punch with a slipping core; during the first blow the conical head is upset; on the second, finally is shaped the hexahedron.

c) Upsetting in two transitions: on the first transition occurs reduction of the rod during pushing of the blank into the die and upsetting of the cylindrical head; on the second, the edge is cut with subsequent ejection of the bolt through the hole in the punch. The die is executed in hard-alloy insert. The method was developed and is applied at the Magnitogorsk sizing plant for bolts in diameter from 6 to 12 mm. With this process at the support surface of the head of the bolt will be formed a burr.

2. Two-position stamping:

a) Two-shock or three-shock upsetting with subsequent cutting of the head (Figs. 96, 106, 107 and 139). This method, remaining at present still the most wide-spread, is characterized by the fact

that the head of the bolt has significant riveting, in consequence of which the bolt is not equi-durable, as may be seen from graphs of degrees of deformation and yield point on Fig. 107.

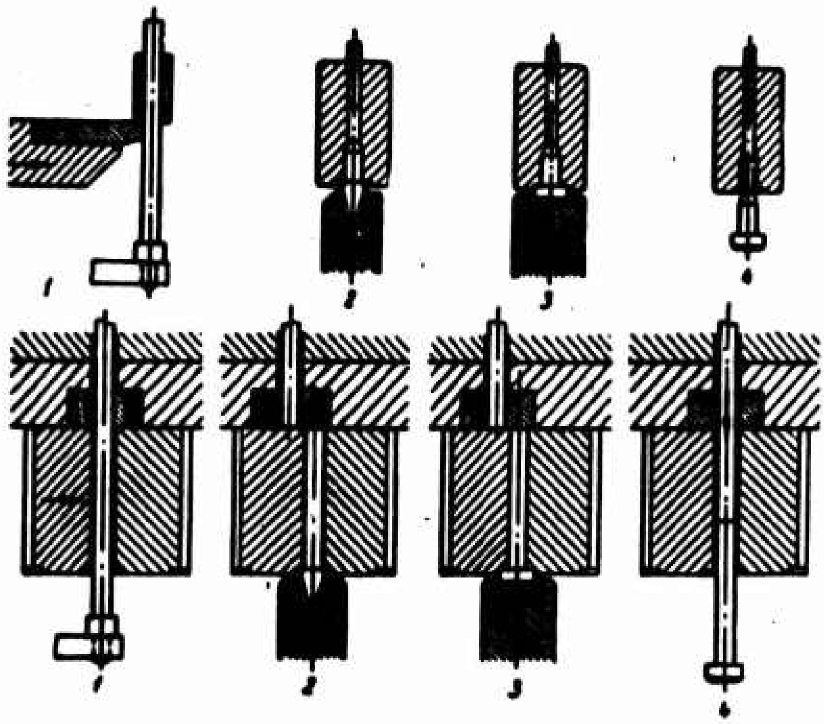


Fig. 106. Diagram of process of upsetting of a bolt with cylindrical head on a two-blow cold upset automatic machine with whole and split dies: 1 – section of blank; 2, 3 – transitions of upsetting; 4 – ejection of stamped part and supply of material.

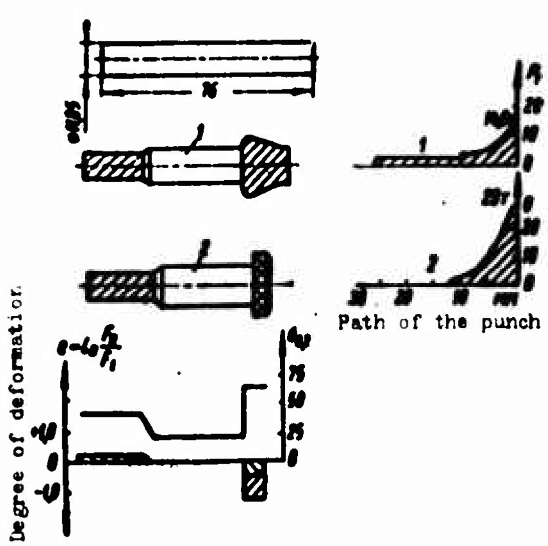


Fig. 107. Change of yield point for two-shock monoposition upsetting depending upon deformation of elements of the blank: 1, 2 – transitions.

b) Wasteless upsetting of the head on two-shock cold-upsetting automatic machines with a whole die (Fig. 108) with subsequent embossing of the hexahedron on an automatic machine for repeated upsetting (method of K. K. Preobrazhenskiy "Red Etna" plant). With this method in case of necessity can be applied intermediate annealing of the stamped blank. During stamping high stability of tool and stability of process is ensured.

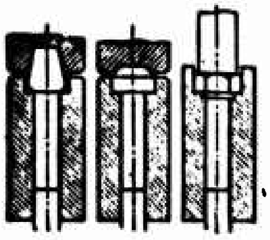


Fig. 108. Diagram of process of upsetting of a bolt with hexahedral head on automatic machines of cold upsetting and for repeated upsetting according to the method of K. K. Preobrazhenskiy (the Krasnaya Etna [Red Etna] plant).

c) Upsetting on a two-position cold-upsetting press-automatic machine of the "Red Etna" plant; embossing of a hexahedral head is carried out in two dies with two transitions (Fig. 109).

3. <u>Three position stamping</u>:

a) Manufacture of bolts on multiposition presses-automatic machines with application of double reduction or rod and faces (Fig. 110). This method gives the possibility of significantly lowering the length of the upset part during manufacture of usual bolts thanks to application of initial material of large diameter. As a rule the diameter of the initial material is taken as 10-15%, and sometimes as 20% larger than the diameter of the threads. In Fig. 110 one may see that the limit of fluidity of a bolt at the head insignificantly differs from the yield point of a rod and rolled part, i.e., with this process a bolt is more equidurable than with usual upsetting.

b) Wasteless obtaining of bolts on a three-position cold-upsetting automatic machine with reduction of the rod. During embossing of a hexahedron slipping cores are used in spring punches.

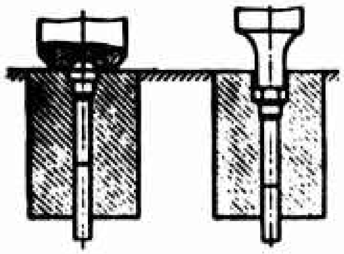


Fig. 109. Upsetting of a hexahedral head on a two position single-strike automatic machine according to the method of the "Red Etna" plant.

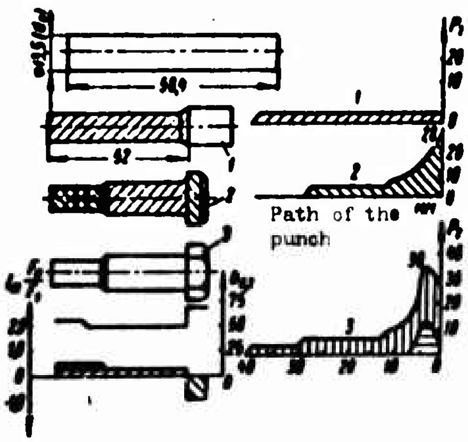


Fig. 110. Variation in yield point and necessary work of deformation in obtaining of a bolt with application of double reduction: 1, 2 and 3 – transitions.

4. Four-position stamping:

a) Obtaining of a hexahedral head on a 4-position press-automatic machine with application of processes of effusion, reduction and cutting of facets (Fig. 111). With this method of manufacture decrease of cross section during pressing constitutes 50-60%, and in exceptional cases can reach to 80%. The process of pressing may be used for a least diameter of initial material near 6 mm and diameter of rod of ready part – 3.5 mm.

Degree of deformation in $\frac{F_0}{F_1}$ for a rod constitutes ~1.25, and for a head, approximately 1. The yield point in this case for the head turns out to be even lower than for the rod. On the whole the difference in mechanical properties of the separate sections of the bolt comparatively is small. The most durable section is the rolled part of the rod.

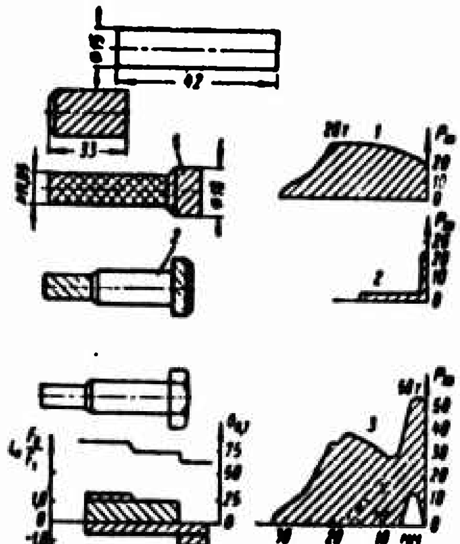


Fig. 111. Change of yield point and necessary work of deformation in obtaining of a bolt with application of processes of pressing and reduction: 1, 2 – transitions; 3 – transition and total work.

b) Wasteless obtaining of a hexahedral head on a 4-position press-automatic machine with application of processes of pressing and reduction. With this method of manufacture of bolts (Fig. 112) punches at the 2nd and 4th positions in the process of preliminary and final embossing of the hexahedral head are spring.

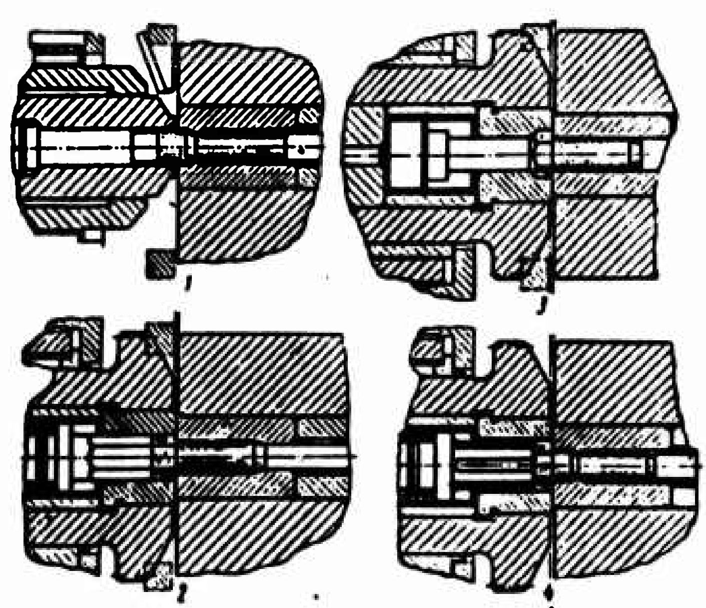


Fig. 112. Wasteless upsetting of hexahedral head at 1, 2, 3 and 4 positions.

Besides the described methods bolts and similar support parts with rods of small length can be prepared on multitransition automatic machines with a revolving die block.

Upsetting of Screws, Terminal Bolts and Rivets

Upsetting of screws with internal hexahedron is done by two methods:

1) on two presses-automatic machines: cold upsetting and for repeated upsetting;

2) on a four-position cold-upsetting automatic machine.

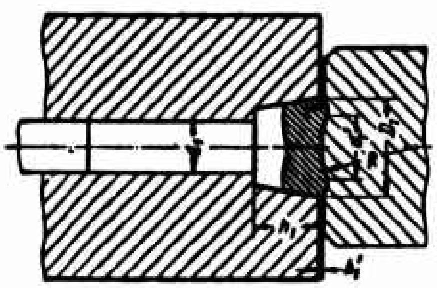


Fig. 113. Upsetting of internal hexahedron – 1st transition.

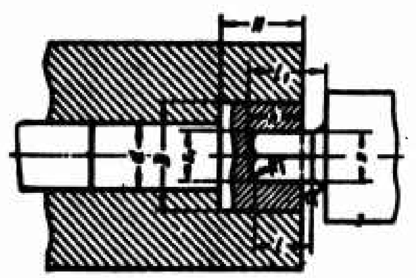


Fig. 114. Upsetting of internal hexahedron – 2nd transition.

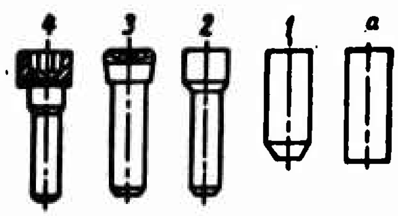


Fig. 115. Upsetting of a bolt with an internal hexahedron on a multiposition cold-upsetting automatic machine: a) section of blank; 1, 2, 3 and 4 – transitions.

During the first method in the beginning on a two-below cold-upset automatic machine with a whole die the head (Fig. 113) is upset. The upset blanks are subjected to annealing (t = 880-900°C), after which on an automatic machine for repeated upsetting or on a vertical crank press in one transition pressing of the internal hexahedron and final embossing of the head (Fig. 114) are carried out.

In the second method (Fig. 115) at the first embossing position subsizing of the cut blank is done with formation education of a face. At the second position the rod is extruded by the method of effusion. The degree of deformation for a screw, for instance, of the diameter 8 mm, constitutes ~60%. At the third position the head

is upset in the form of the frustum of a cone with a spherical marking on the face, at the fourth, the cylindrical head is upset. All four transitions are executed in dies [25].

With this method in connection with application of the process of pressing of a rod the article is obtained comparatively equally-durable and the necessity drops for intermediate annealing for screws made of low-carbon steel.

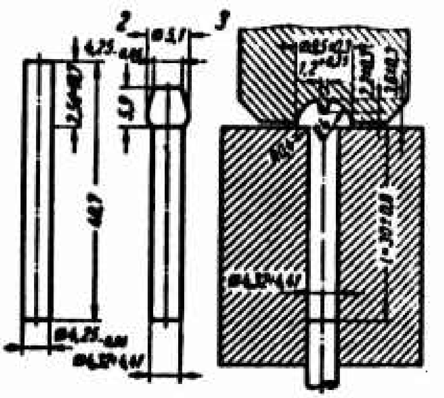


Fig. 116. Transitions during upsetting of a straight slit (1-3).

Upsetting of screws with semicircular heads and straight slits is done on a two-blow cold-upset press-automatic machine with whole die in two transitions (Fig. 116) [11].

Final (finishing) upset punches for semicircular heads of screws with straight slits are sucessfully made by the method of cold extrusion. Extrusion of the bilateral operating profile of the punch is done on a hydraulic or screw press after one depressing in the attachment (Fig. 117) with the help of two hardened master-punches. Then on lateral surface of the insert bare spots are milled. Pressed inserts of steel U10A are thermally processed to hardness HRC 59-61.

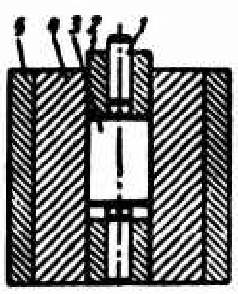
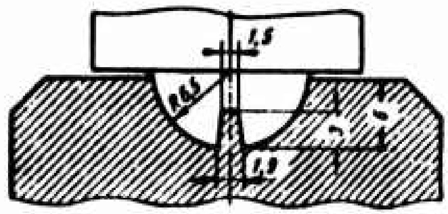
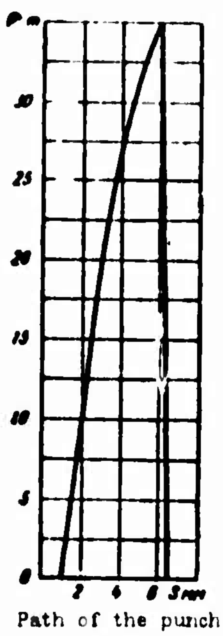


Fig. 117. Extrusion of operating sockets in a punch for upsetting of semicircular heads with a straight slit: 1 – master-punch; 2 – directing bushing; 3 – blank; 4 – casing; 5 – ring.



a)



b)

Fig. 118. Diagram of extrusion of a operating socket and a force graph.

In Fig. 118 is depicted a graph of the force of pressing of a socket in a punch made of steel U10A.

Force of pressing can be determined by the formula

$$P_{выд} \approx \gamma \cdot \sigma_T F,$$

where γ = 3.5-3.75; σ_T – yield point of tool steels in kg/mm^2. During cold volume stamping one should consider the hardness of the metal (Fig. 119). F is the projection of the area of the pressed socket in mm^2.

Flashless cold upsetting of terminal bolts M6 with shaped head are produced from wire in diameter 5.2 mm on two-shock press-automatic machines with subsequent rolling of thread. The operating cavity of the preparing punch constitutes a frustum of a cone with elliptical base. Upsetting of a transition by such a punch ensures obtaining on the second blow of a clear facetted profile of the head of the bolt without a burr [11].

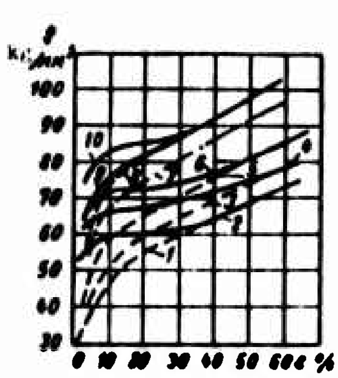


Fig. 119. Hardness curves for pressing carbon steels: 1 – hot-rolled steel, 10; 2 – sized steel, 10 ε' = 20%; 3 – hot-rolled steel 20; 4 – sized steel 20; ε' = 21.5%; 5 – hot-rolled steel 25; 6 – sized steel 25, ε' = 46%; 7 – annealed steel 45; 8 – hot-rolled steel 45; 9 – sized steel 45, ε' = 13%; 10 – sized steel 45, ε' = 30% [14].

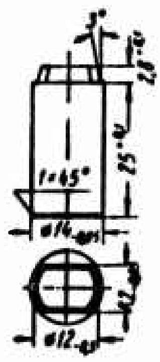


Fig. 120.

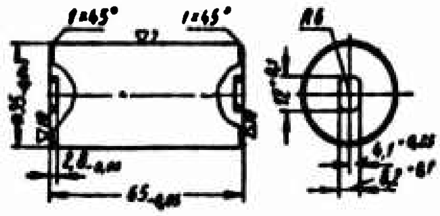


Fig. 121.

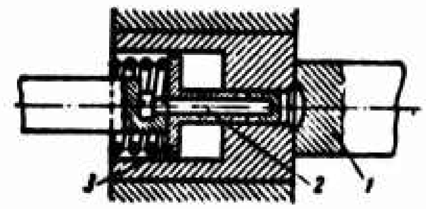


Fig. 122.

Fig. 120. Master-punch for extrusion of an operating socket on a punch for upsetting of a terminal bolt.

Fig. 121. Punches for upsetting of the head of a terminal bolt.

Fig. 122. Monoposition upsetting of a half-hollow rivet on a specialized automatic machine.

The operating cavities of preparing and final punches (Fig. 121) are prepared by the method of cold pressing with the help of master-punches (Fig. 120) of steel U10A, having after hardening and tempering a hardness HRC 59-61. Punches are thermally processed (hardness HRC 60-62).

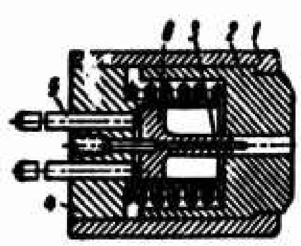


Fig. 123. Die for monoposition upsetting of a half-hollow rivet on a standard cold-upsetting automatic machine: 1 — body; 2 — and 4 — inserts; 3 — piercing needle; 5 — rods; 6 — ejector.

<u>For upsetting of semi-hollow rivets</u> basically three methods are used: 1) monoposition, 2) two-position and 3) multitransition.

Upsetting of semi-hollow rivets by the first method is done on a special automatic machine. A cylindrical blank, cut from wire, at first is set by an upset punch 1 (Fig. 122) on the piercing punch 2; as a result a cavity will be formed. During further movement of the slider forward, upsetting of head (formation of a cone) occurs. During the second blow finally the head of the rivet is shaped; after which the ready part is advanced from the upset die and is removed by the stripper 3.

Monoposition upsetting of semi-hollow rivets is done also on a usual cold-upset two-shock automatic machine with a whole die. In this case the die is prepared from a compound (Fig. 123). During pushing of the blank into the die on the face of the rod will be formed a cavity; then after two blows the head is upset.

The finished rivet is ejected by ejector 6, which is set into motion from the knockout mechanism directly by rod 5.

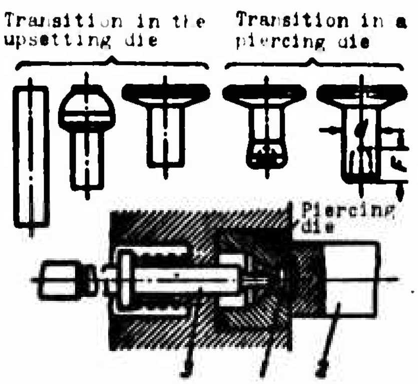


Fig. 124. Two-position upsetting semi-hollow rivet on a specialized automatic machine.

For upsetting by the second method a special two-position cold-upset press-automatic machine is used with two dies (Fig. 124). In the first die is produced upsetting of the head (after one or two blows). Then the rivet is transferred by a spring pin on the axial line of the second die, where initial formation of the cavity occurs by slipping the rod of rivet 1 on the piercing punch ejector 3. Finally the hollow rod is shaped during ejection of the rivet from the piercing die. The part is released the rivet from the piercing die. The part is released during reverse movement of the upset punch 2.

Multitransition upsetting of semi-hollow rivets is carried out on special presses-automatic machines or on vertical crank presses with application of corresponding dies.

An industrial example of an automatic machine for manufacture of semi-hollow rivets in diameter from 1.4 to 3 mm is at the Experimental scientific research institute of forging and pressing machine building (ENIKMASh) at the Voronezh and at the forging and pressing equipment plant imeni XVI Party Congress. On this automatic machine rivets

are upset with length of rod 5-8 mm and diameter of hollowness 0.8-2 mm. The biggest depth of cavity is 2.5 mm. The material of the rivets is sized brass, copper and aluminum wire; productivity of such an automatic machine is 4500 rivets per hour [31].

During movement of the blade forward a section of the blank is made and it is transferred to the line of pushing, position 1 (Fig. 125). Then the following pusher shifts to the extreme front position and the head of the preceding blank is upset position 2. A slider with a block of punches arrives at the extreme front position. Pushing is done from the blade to the die to position 1 of the next blank.

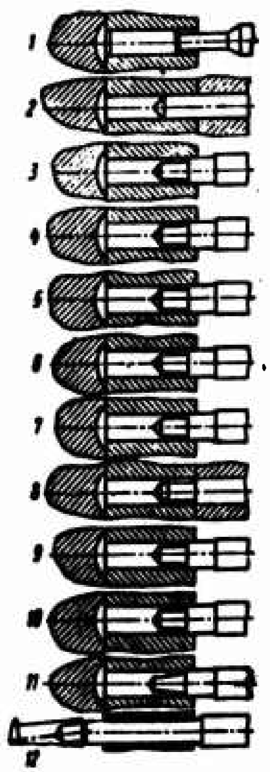


Fig. 125. Multitransition upsetting of a semi-hollow rivet on an automatic machine model A100-0: 1-11 – transitions.

At positions with 3 by 11 is carried out gradual formation of deepening in the rod of the earlier upset blanks, but at position 12 ejection of the ready rivet from the die occurs.

Method of obtaining of semi-hollow and hollow rivets on multiposition die-automatic machines (Fig. 126), established on a universal crank press. In a die it is possible to prepare rivets of steel, brass, copper and other materials. The mechanism of automatic feeding of the wire is mounted in the die. The wire moves to the stop, is cut by the knife, and the blank moves downwards to the socket of the die [15].

In the first transition the blank under the spring punch 3 is put in the die. In the second transition the punch 9 upsets the head, but punch 4 will form the conical deepening in the rod.

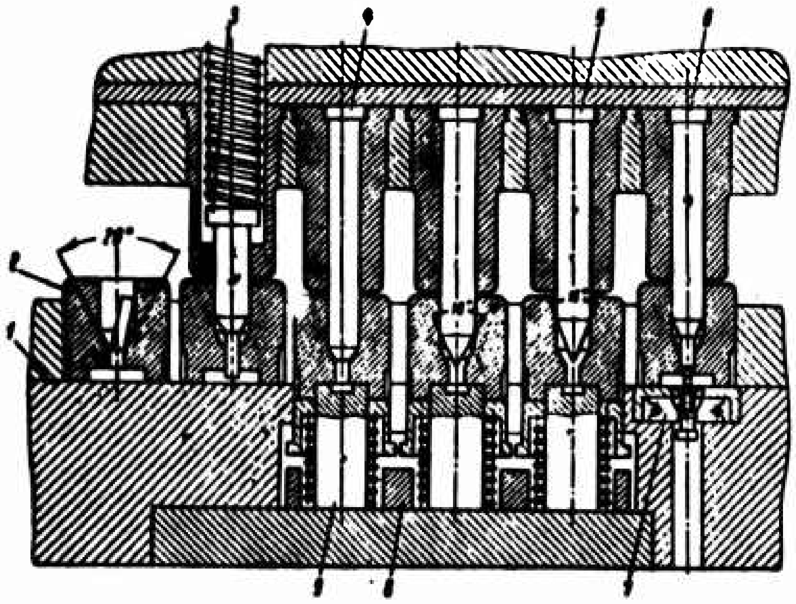


Fig. 126. Multitransition upsetting of a semi-hollow rivet on a vertical press in stamp-automatic machine.

During reverse movement of the slider of the press bushing 8 the force of the spring ejects the die 2 to the level of the upper plane of plate 1 and during further turning of the revolver head on an angular step, the rivet together with the die is transferred to the third transition. Punch 5 during movement of the slider of the press downwards is introduced into the groove of the face of the rod of the rivet. It transfers together with it the die downwards to contact with the head of the rivet with punch 9, and punch 5 presses a conical hole. Due to the difference in angles (at the die the angle is 20°, and at the punches 18° and 16°) during pressing of the hole, metal flows freely upwards into the expanded gap, forming a funnel with the thickened walls above. During ejection of the rivet by punch 6 in transition 5 the die by cylindrical part turns the funnel into a tube and stretches its thickened walls.

During reverse movement of the slider of the press, the rivet is removed by stripper 7 and drops downwards.

The geometry of the dies and punches gives the possibility after two transitions to obtain a hole in depth 7-8 diameters of the hole of the rivet of such materials as steel, brass, copper and others. The material of the punches is steel Kh12F1 and EI790.

Hollow tubular rivets are made just as the semi-hollow ones, but another transition is added – puncture of a hole in the bottom of the rivet.

Volume Stamping of Complicated Parts

Stamping of parts complicated in technological relation is carried out both on multiposition presses-automatic machines in parallel-consecutive action and by the method of consecutive stamping in a number of usual presses (in cold state or with application of electric heating), and also by means of combination of various kinds of stamping operations with operations of cutting.

Upsetting* of the body of the pressure lubricator (Fig. 127). The body is upset from baled steels 10 or 15 in diameter $6.3_{-0.05}$ after three transitions on a three-shock automatic machine 83VA. During upsetting the short part of a part, with which is linked the injector of a grease-press, is in the die. The longer part in the form of the frustum of a cone is molded in three consecutively used punches.

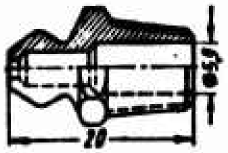


Fig. 127. Body of pressure lubricator.

The annular recession in the head is obtained on counterrecoil automatic machine 12NA; the diameter of the spherical part is $6.7_{-0.2}$.

Further tumbling is done in a drum and, at last, rolling of the thread 1/8" Briggs on a thread-generating automatic machine 12NA.

*Developed and introduced at ZIL.

A step hole is drilled in four transitions with subsequent pressing of the edge by a ball on a special machine.

The ball joint of trucks ZIL (Fig. 128) is prepared by means of cold upsetting of the conical part on a vertical press with force 80 m, reduction of the cylindrical part by thread and formation of conical deepenings on the faces (instead of centering).

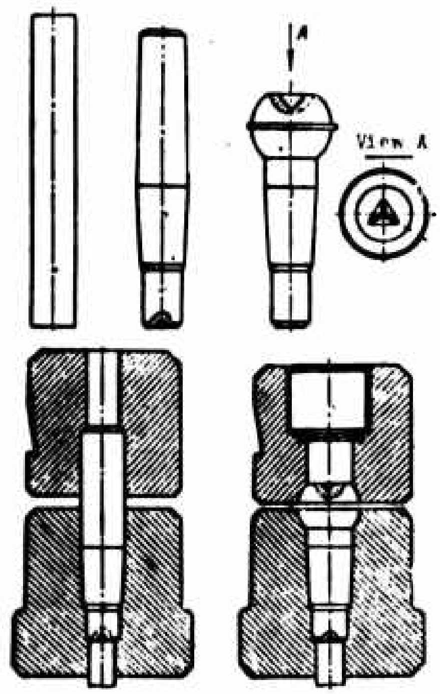


Fig. 128. Transitions and diagram of upsetting of a ball joint.

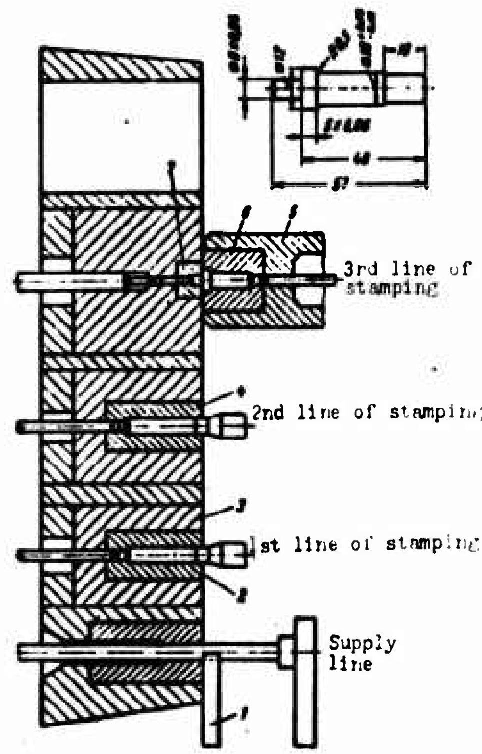


Fig. 129. Multiposition upsetting of a step pin.

In the first operation the cylindrical part is kept unchanged for formation of the spherical head.

In the second operation heating of the cylindrical part of the blank is done by currents of high frequency to 800-900°.

In the third operation, on a vertical press with force 80 m the spherical head is upset with formation on the face of a figure depression.

Multiposition upsetting of a step pin goes by the following way

(Fig. 129). A blank cut by knife 1 and transferred to the first line of upsetting, is pushed in eyelet 2, mounted in die 3. Here first reduction of its end with a degree of pressing $\varepsilon = 43\%$ is done.

When the slider with punches goes back the blank at the appropriate moment is advanced by the ejector from the eyelet into transporting pins, which transfer it from the first line of stamping to the second. At the second line the front end of the blank by means of pushing into eyelet 4 of diameter 6 ± 0.012 mm finally is reduced with a degree of pressing $\varepsilon = 24\%$, and the remaining part of the rod is set to diameter 10 mm.

Further the blank is ejected and is transferred to the third line of stamping. Here the punch 5 with eyelet 6 of hard alloy pushes the blank into insert 7 where formation of the face on the face of the shank of diameter 6 mm occurs; at the same time upsetting of the bead in diameter 12 mm and reduction of the other end of the rod to diameter 9 mm ($\varepsilon = 19\%$) is carried out.

Stamping of short articles of the type of balls and rollers is produced with use either of a spring punch, which stands a certain interval of time, in order to give the knife the possibility of leaving the zone of stamping (Fig. 130a), or by gripping fingers 4, which hold the blank during provement of the knife to the extreme rear position (Fig. 130b). For a more qualitative cut simultaneously with the knife the holding pin-pusher 3 is shifted. On approach of the punch 5 to the blank the pins open quickly passing the punch to the extreme front position [23].

Cold stamping of hexahedral nuts from round sized material is done in four or five transitions. Limits of dimensions of stamped nuts (by nominal diameter of thread) is from M6 to M24. The productivity of automatic machines (theoretical) is up to 125 parts per minute.

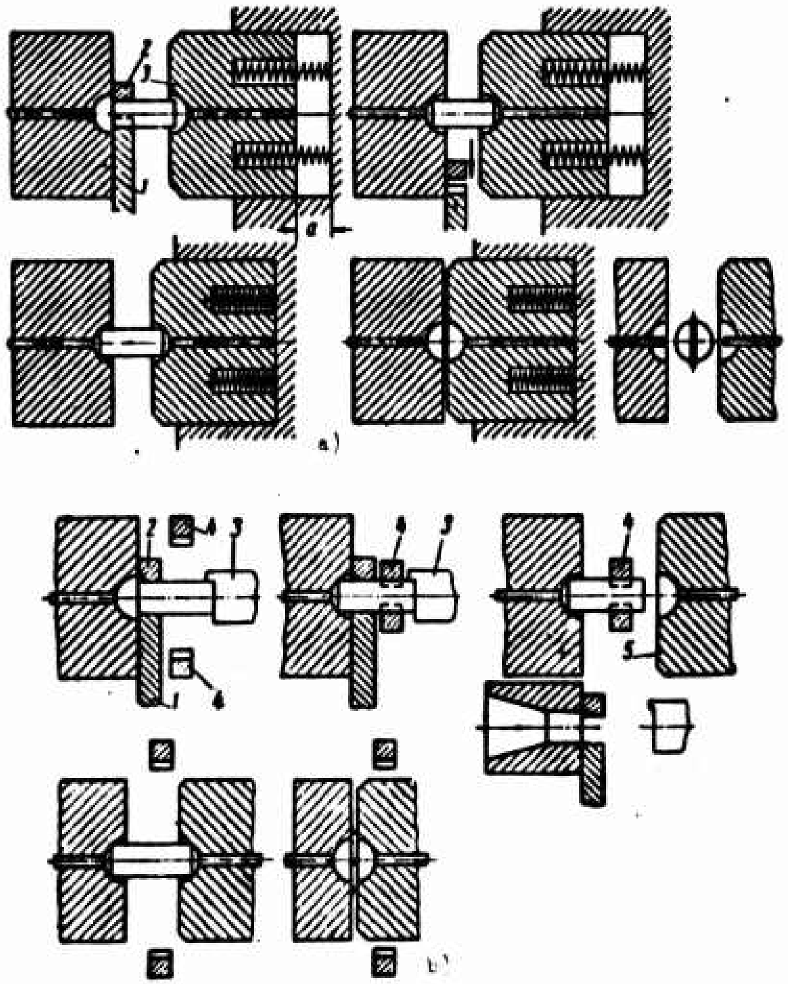


Fig. 130. Methods of upsetting of a ball.

A stamped nut has external and internal faces from two sides; cleanness of surface of it corresponds to the 5-6th classes. After stamping, in the nuts will be cut a thread, their final control and anticorrosive treatment are accomplished.

The firm "Gatebur" has proposed a process of manufacture of nuts from a hexahedral rod on two machines: on a cold-upset automatic machine operational sections are produced; sizing and preliminary stamping of a face; on a vertical press-automatic machine with a bunker load we have final stamping of the nuts.

Nuts with a diameter of thread greater than 24 mm are stamped from round sized rods in the heated state (Fig. 131).

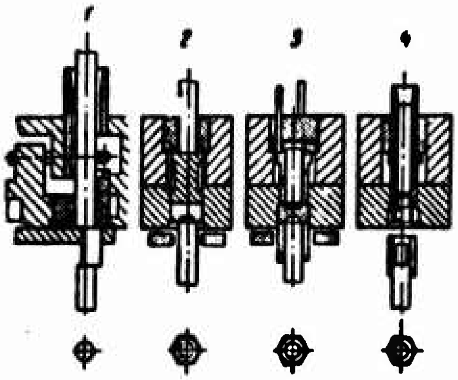


Fig. 131. Diagram of the process of hot volume stamping of a nut: 1 — section of blank; 2 — preliminary stamping of nut; 3 — final embossing of the hexahedron; 4 — puncture of hole.

For stamping of details of more complicated configuration with high degree of deformation and relatively large dimensions the process of upsetting with electric heating may be used; with this method of stamping the length of the upset part of the rod after one movement of the slider may be significantly increased.

Upsetting with electric heating may be carried out on vertical crank presses with a revolver table, equipped with an electric heater arrangement. The specific pressure may be 10-15 kg/mm^2.

At the Gorkiy automobile plant by upsetting with electric heating such parts, for example, as the lever of the steering column and cam bolts for motors of automobiles are made. At the automobile plant imeni Likhachev upsetting of the cam with application of high-frequency heating is done.

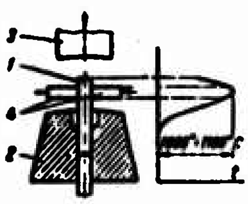


Fig. 132. Diagram of an electric heater during upsetting and the character of distribution of temperature; 1 — blank; 2 — die; 3 — punch; 4 — contacts.

The diagram of an electric heater for exact upsetting and character of distribution of temperature in the blank are depicted in Fig. 132.

An example of complicated volume stamping on a two-shock cold-upset automatic machine can be the drum of a computer (Fig. 133). The shape of the initial blank is flat hexahedron, but from an aluminum band or strip. The flange and hole are formed during stamping [9].

Examples of transitions during cold volume stamping of details of type of plates, rings,

washers and caps are shown in Figs. 134 and 135 [2].

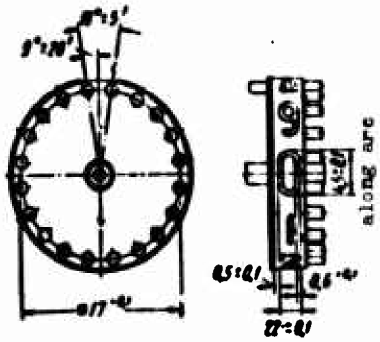


Fig. 133. Drum of a computing mechanism.

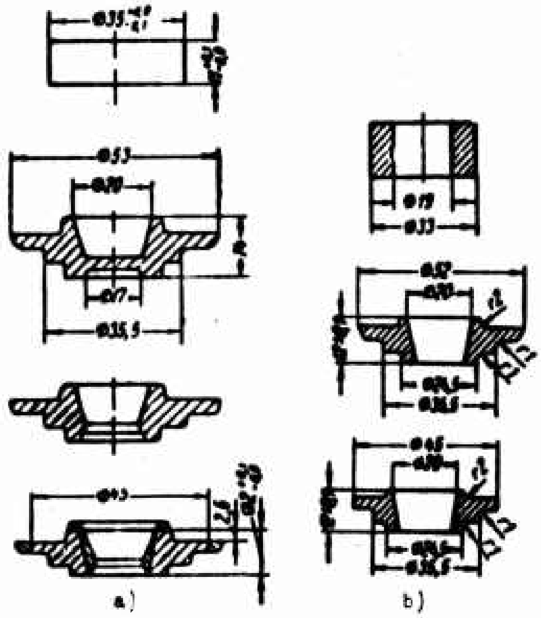


Fig. 134. Transitions during cold volume stamping of parts from solid a and hollow b blanks.

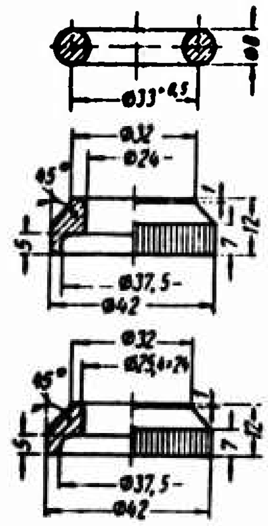


Fig. 135. Drum of a computing mechanism.

Of great interest is the obtaining of parts complicated in configuration by means of radial introduction of punches in the body of the blank (Fig. 136 and 137). The die in Fig. 138 is installed on the table of the press; the article is brought in with the help of a lever or pneumatically. Extrusion of parts proceeds at comparatively low specific pressures – from 120 to 150 kg/mm^2. Reamers are obtained with allowance under grinding of 0.3-0.4 mm.

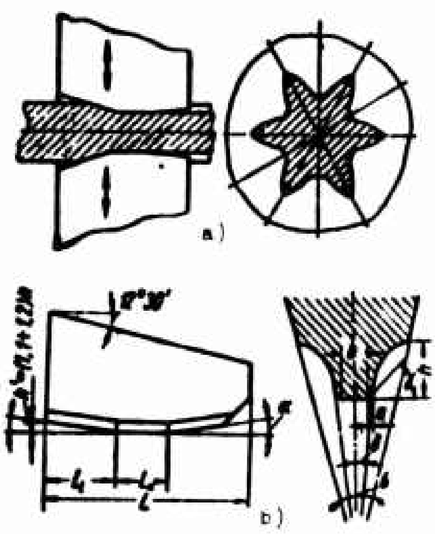


Fig. 136. Diagram of a radial volume stamping and profile b of punch.

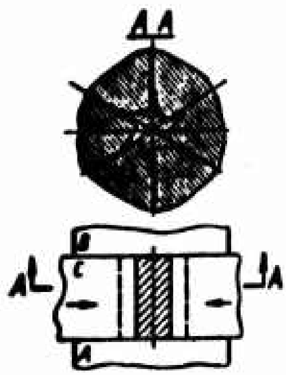


Fig. 137. Diagram of radial volume stamping of a reamer.

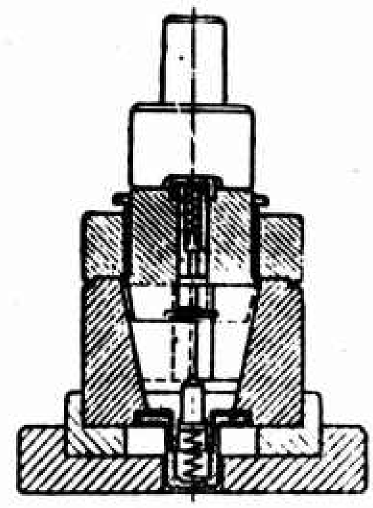


Fig. 138. Stamp for radial stamping.

By the indicated method in the Czechoslovakian Socialist Republic articles are processed made of nonferrous metals, carbon, tool and high-speed cutting steel. Testing of wear of articles, obtained by the method of radial pressing, showed that as compared to usual, the wear of them is 20% less.

The productivity of the new method in 30-40 times higher than milling, economy of material 20-40% depending upon the shape of the article.

Reduction (Pressing) of the Rod and Cutting of the Upset Parts Along the Required Contour

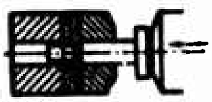
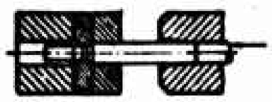
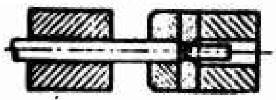
The process of reduction of the rod is carried out in most cases simultaneously with cold upsetting or cutting, and also as independent operation. Methods of reductions are given in Table 68.

Cutting of upset articles on the required contour is done on special presses-automatic machines or on vertical crank presses by two methods:

1) pushing of blank into a motionless die by rod forward;

2) pushing of the blank into a motionless die by head forward.

Table 68. Methods of Reduction

Method of reduction	Place of installation of eyelet	Assignment	Degree of pressing during reduction *
 a)		 b)	 c)
Pushing of blank in motionless eyelet (direct method): a - before cutting margins; b - before upsetting; c - form of hole of eyelet;**	Die	1. Pressing and sizing of rod on rolling thread 2. Sizing of the smooth part of the rod of the bolt 3. Pressing of the rod, replacing the first transition of upsetting (blank is pressed to that part, where the head should be formed) 	
Moving of eyelet to motionless blank (turned method)	Punch	1. Pressing of ends of long pulls on rolling of thread 2. Pressing and sizing of part of rod during combined treatment of complicated metals	$\lambda = \frac{F_0}{F_1} = 50$-60% may be attained on double or triple pressing

Note: During pressing of a rod a bend can occur in the reduced part; in avoidance of this the eyelet is made with a guide part, when $\gamma_2 = 0$, y is equal to the length of the directrix.

*F_0 — area of rod before reduction; F — area of pressed part of rod.

**$\gamma_1 \approx \gamma_2 \approx 25$-$30^{\circ}$; y = 0.8-3 mm.

The first method is the most wide-spread. During cutting by this method (Fig. 139) the blank, obtained on a cold-upset press-automatic machine and sent from the bunker to the axial line of cutting in the beginning is pushed by the butt of a mobile die into a motionless die 2, and then (at the end of the operating movement of the slider) cutting of the edges occurs, and further, through the hole of the mobile die and cavity in

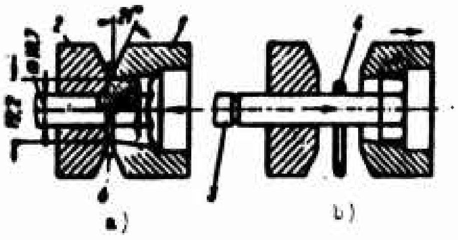


Fig. 139. Process of cutting.

the slider it is ejected by rod 3 into the box for ready articles. Metal cutoff in the shape of a wreath 4 at the beginning of departure of the mobile die drops downward, into a separate box. If simultaneously with cutting of margins it is required to produce reduction of the rod, then in the die 2 an eyelet is inserted.

Formulas for determination of deforming forces during cold upsetting and stamping are given in Table 69.

The above considered operations in cold volume stamping upsetting, reduction, pressing and cutting are carried out on forging and pressing automatic machines of different models and type sizes, the description of which with brief characteristics is given in Table 70.

Table 69. Formulas for Determination of Deforming Forces (P) During Processes of Cold Upsetting and Cold Volume Stamping.

Process of deformation	Formula	Source
Upsetting of heads in the form of solids of revolution	$P = 2\sigma_{Tq}\left(1 + 0.05\frac{D}{h_{npue}}\right)F.$ Approximate formula $P = 0.5\sigma_T D^2$ (σ_T в кГ/мм², D в см)	[23] [23]
Upsetting of hexahedral heads	$P = 0.785 D^2\left(1 + 0.2\frac{D_{ш}}{h} + 0.06\frac{D_{ш}}{g}\right).$ where $D_{ш}$ - given diameter of head in mm; $D_{ш} = \sqrt{0.785\cdot\frac{V}{h}}$	[30]
Closed piercing (reverse pressing)	$P = \left[k_1 + \frac{(35 - e^0)^2}{k_2}\right]F$	[30]
Reduction	$P = \left\{\frac{\sigma_T^{\circ}\cdot x}{x-1}\left[(1-\varphi)^{1-x} - 1\right] + \frac{4\sigma_{Tq}\mu b}{d_1}(1-\varphi)^{1-x}\right\}F_0.$ where $\sigma_T^{\circ} = \frac{\sigma_T + \sigma_{Tq}}{2}$; $x = \frac{\operatorname{tg}\alpha + \mu}{(1 - \mu\operatorname{tg}\alpha)\operatorname{tg}\alpha}$	[8]
Straight extrusion (effusion)	$P = \left[k_1 - \sqrt{k_2(k_1 - q)}\right]F$	[30]
Ejection after upsetting	$P = p\cdot\mu\pi d l_{pacч}$	

Table 69. (Continued)

Ejection after reduction	$P = \sigma_{Tq} \pi d \mu h$	(6)

In the formulas the following designations are assumed:

σ_T – yield point of initial material in kg/mm^2;

σ_{Tq} – true resistance to deformation taking into account hardening (see Fig. 119);

D – diameter of head;

$h_{прив}$ – given height of head;

$$h_{прив} = \frac{h_0 d_0^2}{D^2};$$

h_0 – length of upset part of blank;

d_0 – initial diameter of blank;

F – area of projection of stamped blank, perpendicular to the axis of stamping;

a – thickness of wall;

h – height of cylindrical or hexahedral head;

k_1, k_2, k_3 – coefficients, determined from tables;

p – specific pressure on walls of die, $p \approx 25\ kg/mm^2$.

Range of degree of deformation in %	Steel with content of C in %	k_1	k_2
From 0 to 35	0.15 0.45	187 200	17.4 10.8
Over 35	0.15 0.45	190 230	17.0 4.85

Part	Steel with content of C in %	k_1	k_2	k_3
Without cavity With cavity	0.15 0.45 0.15 0.35	233 216 306 342	1125 880 1040 1370	100 85 90 80

Table 69. (Continued)

Form of steel is determined only by content of carbon. Content of Mn and Si does not render influence on the magnitude of resistance to deformation.

$y = d - d_2$ — magnitude, characterizing rounding of angles;

q — degree of deformation during reduction and pressing;

b — width of belt of reducing eyelet;

F_0 — initial area of section of blank before reduction;

l — length of rod of upset article;

d — diameter of rod of upset article;

μ — coefficient of friction, equal to 0.15;

$l_{расч}$ — chosen by the following method:

a) for articles, for which $\frac{l}{d} \geq 4$, $l_{расч} \approx 4d$;

b) for articles, for which $\frac{l}{d} < 4$, $l_{расч} = l$.

Table 70. Characteristic of Cold-Upset Presses-Automatic Machines by Types of Forging-Presses in the Years 1960-1965

Presses	Model	The biggest diameter of rod in mm	The biggest length of rod in mm	Theoretical productivity in pieces/min
Single-stroke with whole die	— — A111A — A1120 A1121	2,5 4 6 8 10 12	4—20 6—[illegible] 10—[illegible] 12—[illegible] 16—70 16—90	400; 450 [illegible]; 300 [illegible]; 220 180 120 100
Single-stroke with split die	— A1231 —	6 12 20	16—72 [illegible]—[illegible] [illegible]—200	170; 200 [illegible] [illegible]; 75
Single-stroke hot-upset with split die	— A315 —	[illegible] [illegible] [illegible]	[illegible]—250	[illegible]

Table 70. (Continued)

Presses	Model	The biggest diameter of rod in mm	The biggest length of rod in mm	Theoretical productivity in pieces/min
Two-shock with whole die	— AB120 A121B AA129	2,6 4 6 8	4—20 6—32 6—32 10—65	300 150; 190 115; 140 90; 110
Two-shock with split die	— —	4 6	8—48 16—75	190; 225 135; 165
	A1419	8	16—75	105; 120
	A1420	10	22—120	85; 95
	A163B	12	25—145	70; 80
	A164A	16	35—190	55; 60
	— —	20 25	40—200 60—200	50; 55 45; 50
Multiposition combines	AA101 AA102 A1920 A100 A104 A105 A106	6 8 10 12 16 20 24	10—60 12—75 90 25—100 30—125 — —	— 90; 110 — 80; 70; 100 40; 70 — —
Multiposition	AA191 AA190 A1720 A193 AA194 — —	6 8 10 12 16 20 25	10—60 12—77 — 16—100 25—120 — —	— 90—120 — 70—90 60—80 — —
Cut	— AA231 A233A A235	6 10 16 25	12—50 15—60 25—210 25—200	150 110 65; 75 50
Multiposition nut cold-upsetting specialized	A1818 AA411 A412 A1822 — A1824	6 8 12 16 20 27	—	120 100 80 65 50 42
Nut hot-landing specialized	— A250	25 36	—	— 60; 70
For stamping of balls and rollers specialized	— A141A A142A A145A A145 A148A A148	2,5 2—4,8 4,8—7,1 22 22 24,3 24,3	— 6,3 • 10 • 16 • 20 • 25 • 30 •	— 200 — — — 70 70

Table 70. (Continued)

Presses	Model	The biggest diameter of rod in mm	The biggest length of rod in mm	Theoretical productivity in pieces/min.
Thread-generating with flat screw dies	—	2.6	3–25	160–200
	A2412	4	4–40	160
	AA251	6	8–60	• 140
	—	10	12–100	—
	AA253	12	18–120	85–120
	—	16	22–160	—
	AA255	20	30–200	—
	A2424	25	40–200	—
Wire - nail-making specialized	A711	1.2	7–25	900
	A712	2	20–50	800
	—	3	20–80	620
	A714	4	20–110	520
	—	5	25–150	—
	AA715	6	40–200	400
	—	8	—	—

*The biggest diameter of ready article in mm.

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CHAPTER III

TECHNOLOGY OF WELDING PRODUCTION

TECHNOLOGICAL BASES OF CONSTRUCTION OF WELDED MACHINE PARTS

Requirements of rational construction of welded machine parts and units may be subdivided into general, for all methods of welding, and special.

General Requirements for Construction

1. Necessity of construction taking into account a general flow chart (Fig. 1) and rational methods of welding (Table 1).

I	III	II
Blank of pass with final machining	Blank of parts (machining is limited to preparation of edges	Blank of parts with partial machining
↓	↓	↓
Assembly	Assembly	Assembly
↓	↓	↓
Welding	Welding	Welding
↓	↓	↓
Dressing	Heat treatment	Final machining
	↓	
	Machining	

Fig. 1. Model flow charts of manufacture of welded parts.

Table 1. General Characteristic of Basic Methods of Welding

Welding	Most frequently welded materials	Recommended thickness, mm, or area of section of welded parts, mm²	Basic types of welded joints	Space position of welded seams	Where used
Manual electric arc with metallic electrode (V)	Steel Cast iron Alum. and its alloys Copper Bronze Hard alloys	≥ 1.5 — ≥ 1 ≥ 1 — —	Butt-to-butt (B/B), overlap, T-section, flanging, hardfacing B/B, hardfacing B/B B/B, flanging B/B, hardfacing Hardfacing	Any Lower " " " "	In all branches of machine building
Automatic (VV) and semiautomatic (V) with melted metallic electrode under a layer of flux	Steel Alum. and its alloys Copper Titanium	≥ 3 ≥ 6 ≥ 4 ≥ 2	B/B, overlap, T-section, electro-rivet, hardfacing B/B B/B, hardfacing B/B	Lower, possibly vertical Lower " "	In all branches of machine building with extended seams
Electroslag welding (VV)	Steel Cast iron	≥ 40 —	B/B, T-section B/B	At an angle less than 45° to vert. Annular	In heavy machine building for welding thick metal
Manual electric arc with carbon (unmelted) electrode (VV)	Steel (low carbon) Aluminum Copper	≤ 4 ≥ 1 ≥ 1	Flanging ≤ 3 мм — flanging ≥ 3 мм — B/B ≤ 3 мм — flanging ≥ 3 мм — B/B	Any, except ceiling Lower "	Limited to unimportant joints
Automatic, with unmelted electrode (carbon-copper; tungsten-aluminum) by layer of flux (V)	Copper and alum. Titanium	≥ 2 ≥ 2	B/B B/B	Lower "	Limited to welding of nonferrous metals
Atomic-hydrogen (U)	Alloyed steel	≤ 8	B/B, T-section, flanging	Any, except ceiling	Limited to welding of alloyed steels (replaced by argon-arc welding)
Electric arc with unmelted electrode in protective medium (argon) (V)	Stainless steel, alum. & its alloys, magnesium alloys, titanium	≤ 4	B/B, T-section, flanging, electro-rivet	Any, except ceiling	Widely used for welding of responsible structures of alloyed steel and light alloys
Electric arc with melted electrode in protective medium (argon) (VV)	Stainless steel, light alloys, titanium	≥ 3	B/B, T-section, flanging, electro-rivet	Lower annular	The same
Electric arc with melted electrode in carbon dioxide medium*	Steel	≥ 1.5	B/B, T-section	Any	Universal method of automated welding of structural steels, widely used in all branches of machine building

Table 1 (Continued)

Welding	Most frequently welded materials	Recommended thickness, mm, or area of section of welded parts, mm^2	Basic types of welded joints	Space position of welded seams	Where used
Gas (U)	Steel Cast iron Alum. & its alloys, copper, bronze, brass Hard alloys	≤ 3 — ≤ 10 —	B/B, flanging B/B, hardfacing B/B, hardfacing B/B, flanging Hardfacing	Any Lower » » »	For welding thin metal (gradually replaced by gas-electric welding methods)
Gas pressing (V)	Steel	Up to 25 000 mm^2	B/B	Lower*	Limited to transport machine building
Thermite	Steel	Up to 200 000 mm^2	B/B	Lower	Practically unused in machine building
Contact joint, by fusion (V)	Steel, alum. & its alloys Titanium Heat-resisting alloys	Section of steel up to 25,000 mm^2** with thickness of more than 0.7 mm	B/B	Lower*	Widely used in automobile, tractor, and tool industry, boiler making, chain industry, etc.
Contact joint, by resistance (VV)	Steel	Wire with diameter up to 10 mm	B/B	Lower*	Limited (production of small chains, wire stitching)
Point (VV)	Low-carbon steel Structural alloy steel Stainless steel Alum. alloys Heat-resisting alloys Magnetic alloys Titanium	≤ 12*** ≤ 10*** 6**** ≤ 6 ≤ 3 ≤ 7 —	Overlap » » » » » »	Using portable devices (tongs, guns, etc.), any	Widely used in mass production of thin metal parts
Roller (V)	Pickled Hot-rolled low-carbon steel Stainless steel Alum. alloys Copper alloys Heat-resisting alloys	≤ 3 ≤ 2.5 ≤ 3 ≤ 4 ≤ 3 ≤ 2.5	Overlap » » » » »	Lower* » » » » »	The same
Relief (VV)	Low-carbon steel, stainless steel	0.5–4	Overlap	Lower*	The same
T-shape (contact)	The same	≤ 150 mm^2 (section of welded joint)	Overlap Joining of pipes by T-section at an angle of 45-90° (by capacitor discharge)	Lower*	The same

* Position during welding is usually lower, and is determined by the construction of the welding machine.
** On serial equipment, to 10,000 mm^2.
*** On serial equipment, to 6 mm.
**** On serial equipment, to 3 mm.

Table 1 (Continued)

Welding	Most frequently welded materials	Recommended thickness, mm, or area of section of welded parts, mm^2	Basic types of welded joints	Space position of welded seams	Where used
Cold (VV)	Aluminum Copper and copper with aluminum	≤ 10 ≤ 80 mm^2	Overlap B/B The same	Lower* "	Limited to power machine building
By friction	Structural and instrument steel Aluminum, copper, and their alloys	≤ 6000 m^2	B/B of round rods or tubes The same	Lower*	Introduced into the production of tools, automobile parts, farm machinery
By ultrasound (point or roller)	Alum. & its alloys Copper Plastic	To 1—1.5 mm To 0.5 mm	Overlap — —	Lower*	Process in the acceptance stage
By electron beam in a vacuum	Refractory and chemically active metals (molybdenum, zirconium, etc.)	—	Overlap B/B	Lower	For welding of refractory metals and, in individual cases, for welding of high-alloy steels and alloys
Vibration arc	Steel	—	Hardfacing	Lower	In repair, for restoration of worn-out parts
With induction heating	Steel	To 4 mm	B/B (longitudinal seam of pipes)	Lower*	Introduced for welding of pipes in boiler making
With heating by radio-frequency currents (to 450 cps)	Steel Aluminum	To 4 mm	The same	The same	In pipe production

NOTE: There must be high accuracy in preparing and collecting the parts for automatic flux welding, contact butt welding and roller welding. The output is indicated thus: V — high, VV — very high, U — medium.

* The position during welding is usually lower, and is determined by the construction of the welding machine.

Welding without subsequent machining (Fig. 1, I) (so-called hot assembling). For instance: 1) welding of suspension of a spring with flange of housing of rear semiaxis of a passenger automobile; the suspension 1 (Fig. 2a) with a pressed steel bushing 2 and finally treated pin 3 is welded butt-to-butt with a flange 4; 2) welding of finally treated bushings to turning platform of walking excavator, consisting of three sections with general dimension 20 × 11.5 m [1]; bushings 1 (Fig. 2b) were installed on rigid mountings 2, ensuring coaxialness and required distance between bushings.

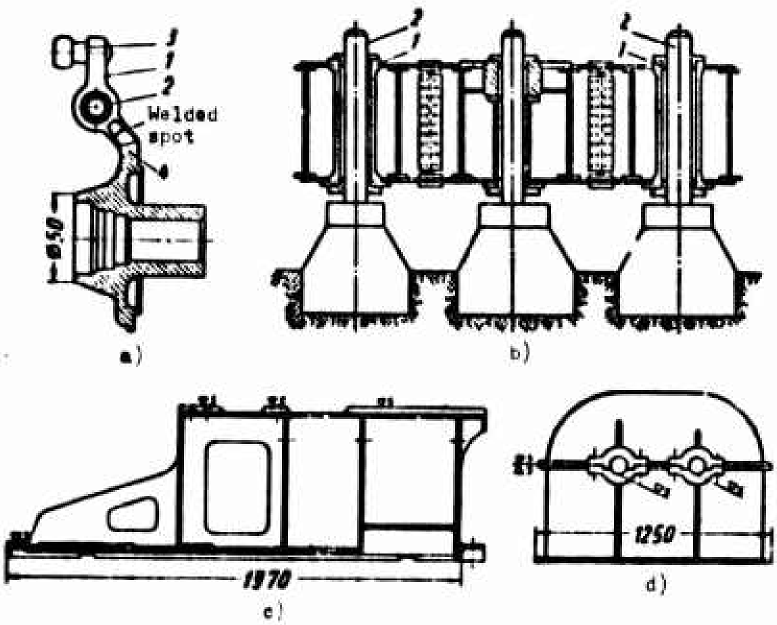


Fig. 2. Examples of application of basic technological variants of manufacture of welded parts.

Advantages of hot assembling — easing of machining and unloading of big machines; deficiency — difficulty of guarantee of accuracy of welded unit. Region of application — units of low accuracy with small volume of welding or very big units.

During electroslag welding control of deformations is possible

ensuring manufacture of big parts of 4-5th class of accuracy from preliminarily treated blanks. After welding accuracy can be obtained in linear shift within the limits 0.2-0.3 mm and with respect to angle of rotation ±0.0025 [2].

Welding with thermal treatment and machining of the ready unit (see Fig. 1, II). Example — welded flock-on metal-cutting machine (Fig. 2c). Advantages — accuracy and immutability of geometric shape of the unit, absence of internal stresses. Deficiencies — high labor consumption and long industrial cycle. Area of application — exact units, units with large volume of welding.

Welding with dismembered machining (Fig. 1, III). Example — welded body of a reductor (Fig. 2d); bodies of bearings are processed in the rough before welding, their finish boring is carried out in assembled form after milling of planes of linkage of both halves of the body of the reductor. Advantage — acceleration of machining and decrease of load of big machines. Deficiency — complication of path of parts in workshops during production. Region of application — units of large dimension of high accuracy.

Comparative profitableness of different methods of welding depends on the conditions of its fulfillment (dimension and weight of parts, seriality of production and others). Some approximations during selection of methods of welding by solid seams of construction steel small and large in thickness are given in the graph in Fig. 3 [3]. Steel by thickness 6-30 mm is usually most profitably welded under flux or in an environment of carbon dioxide.

2. Bringing to a minimum the volume of welding operations by the following means: a) decreases the number of parts in a welded unit (replacement of pack of thin sheets by one thick one, Fig. 4a;

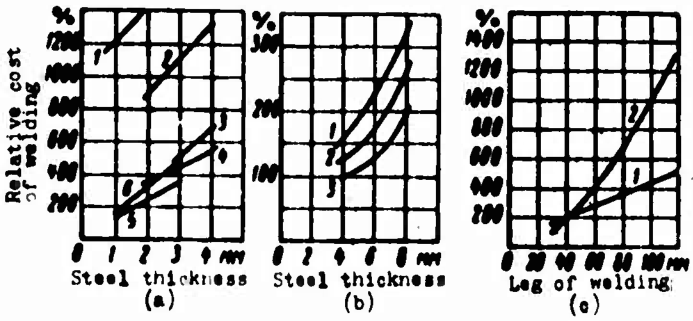


Fig. 3. Relative cost in percents: a) welding of steel of thickness 1-4 mm (1 – gas welding; 2 – one-sided manual arc welding; 3 – semi-automatic under flux; 4 – semi-automatic in CO_2; 5 – contact roller welding of purified hot-rolled steel; 6 – the same, pickled steels taking into account its higher cost); b) welding of steel of thickness 4-8 mm (1 – arc welding by electroded TsM-7; 2 – welding under flux; 3 – welding in CO_2); c) welding of steel of thickness more than 30 mm (1 – electroslag welding; 2 – welding under flux).

application of bending in place of welding, Fig. 4b; application of space stamping in place of cutting and rolling, Fig. 4c; replacement of ribs of rigidity with stamped reinforcements Fig. 4d); b) decreases the amount of fused metal (replacement of intermittent seams 1 with roll 2k and volume of hard-facing W_1, with solid seams 2 with roll k and volume of hard-facing $W_2 = 0.5\ W_1$, Fig. 4d; application of minimum angles of division of edges ensuring full penetration, and also joinings without bevel of edges; application of electrodes and additive materials, ensuring high durability of joinings without cover plates also with minimum section of seams).

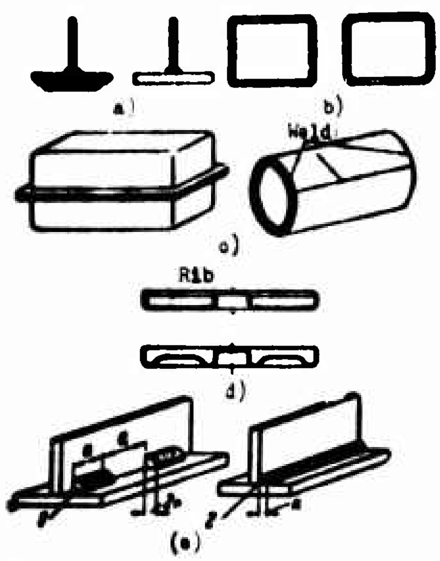


Fig. 4. Methods of decreasing volume of welding operations.

3. Bringing to a minimum deformations and stresses, evoked by welding, means: a) decrease in number of welded seams and volume of fused metal (see above); b) as far as possible symmetric location of seams with respect to center of gravity of the welded element (location of seams on Fig. 5a corresponds to this requirement, in Fig. 5b, does not correspond); c) nonadmission

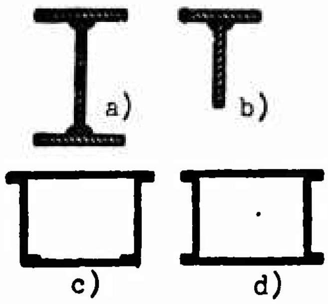


Fig. 5. Types of welded sections.

of dense location of welded seams with frequent crossing; d) location of seams, as far as possible allowing assembly of the entire unit before beginning welding (construction with point seams, shown in Fig. 5c, does not satisfy this requirement, since during obligatory welding of internal seams before welding of external element significant deformation is obtained; construction in Fig. 5d is better — here welding is possible in any sequence).

4. Protection of treated surfaces of parts from damage during welding by means of distribution of welded seams at sufficient distance from such surfaces (during welding of a bushing, Fig. 6a, its

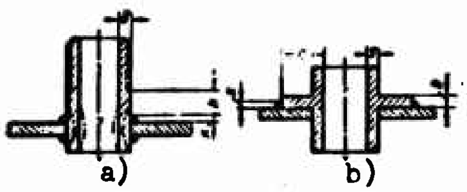


Fig. 6. Variants of welding of bushings and stub pipes.

internal dimensions are changed, as is shown by the dotted line, and accuracy is lost); during welding of preliminarily cut stub pipes, distance h should be $5\delta \le h \le 5k$); construction in Fig. 6b allows preservation during electric arc welding of passage diameter of bushing for $b \ge \delta$ and $c \ge 3k$.

5. Distribution of all critical welds allowing in the completed construction their inspection and checking.

Special Requirements for Construction

Manual electric arc welding. Methods of preparation of edges are determined by thickness and brand of weld metal, type of joint, its spatial position during welding, and the technological process of welding (mono- or bilateral welding).

Basic methods of preparation of edges of steel parts for butt joinings in all positions, except horizontal, are shown in Fig. 7a-d;

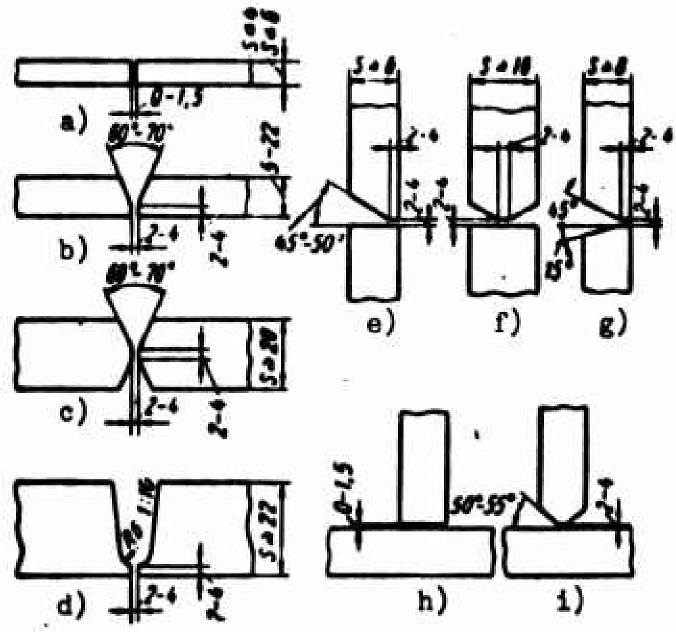


Fig. 7. Basic views of preparation of edges during manual electric are welding.

for butt joinings in the horizontal position, in Fig. 7e-g; for T-connection, in Fig. 7h, i. Maximum thickness of parts, welded manually without bevel of edges, is equal to 4 mm for one-sided and 6 mm for bilateral welding of steel.

Preparation of edges of assembly butts as far as possible should anticipate their welding in lower or vertical position (Fig. 8a).

Welding of aluminum and its alloys butt-to-butt usually is done without bevel of edges with a gap of 1-1.5 mm.

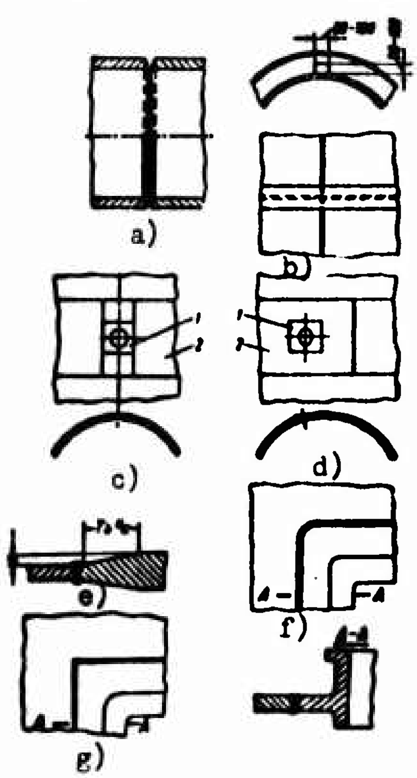


Fig. 8. Structural peculiarities of thick-welded articles of large size.

Minimum roll k_{min} of shaft seams, ensuring satisfactory penetration, is determined depending upon the thickness of the welded elements, and namely:

σ in mm		k_{min} in mm
<4	....	3
4-8	....	4
9-15	....	6
16-25	....	8
>25	....	10

During welding of thick-walled articles the following must be assured:

a) possibility of welding of basic joint seams without interruptions, for

which in intersecting their elements of construction window (Fig. 8b) of dimension 80-100 mm must be foreseen;

b) free shrinkage of seams (linkage of body 1 of a poured hatch with wall 2 in Fig. 8c satisfies this, and in Fig. 8d it does not satisfy this requirement);

c) smooth transitions in butt joints from thick detail to thin (Fig. 8d);

d) smooth transitions in angles (linkage in Fig. 8e satisfies, and in Fig. 8g it does not satisfy this requirement)

Automatic and semiautomatic arc welding under flux. Preparation of edges of steel parts is determined by their thickness and technological process of welding (see p. 270). Sheets from aluminum and its alloys in thickness to 25 mm are welded without bevel of edges.

Position of seams in space may be lower or slightly slanted (angle of inclination to 3°).

The outline of seams during automatic welding is rectilinear and annular, during semiautomatic — any.

Increase of productivity of automatic welding (mainly at the expense of decrease of auxiliary time) is attained: a) monotypicity of welded joints; b) location of seams, requiring minimum amount of edging of welded article (for instance, construction in Fig. 9a requires one reedging without readjustment of automatic machine, but less successful construction in Fig. 9b requires multiple readjustment for the same amount of reedging); c) facility for delay of flux, for example, the joint in Fig. 9c is more convenient than the joint in Fig. 9d, requiring special devices for retention of flux); d) possibility of unhindered advance of welding automatic machine along the seam (box-like section of balls with internal diaphragms 1 in Fig. 9e

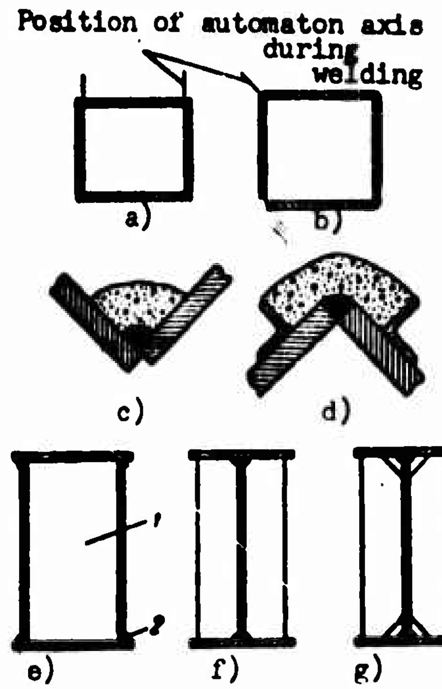


Fig. 9. Peculiarities of welded units during automatic welding under flux.

allows welding on the outside without interruptions of the belt seams 2; the I-beam section in Fig. 9f is less convenient; this inconveneince is removed by welding of ribs with cut angles in Fig. 9g after welding of belt seams).

The minimum diameter of article, allowing automatic welding from within of longitudinal and annular seams with application of serial equipment, is 800 mm. An attenuator with extended neck (to a welding automatic machine) allows welding of internal seams in articles of significantly smaller diameter.

The minimum diameter of external annular seams during automatic welding under flux is near 100 mm. During welding of articles of small diameter, not allowing application of linings (steel, copper or flux), construction of the joint should prevent the flow of molten metal (constructions in Fig. 10a correspond to and in Fig. 10b do not correspond to this requirement). During welding of annular seams of small diameter the depth of penetration decreases and division with an angle up to 90° has to be used, also trapezoidal divisions (Fig. 10a).

Electroslag welding. Type of joint – butt or T-connection. The edges are planned or finished with a gascutting automatic machine, without bevel. Assembly of the joint is with a gap of 22-30 mm. Thickness steel is 50-500 mm and above.

Types of section of welded elements are rectangle, trapezoid, ring or profile, limited by arcs of circumference.

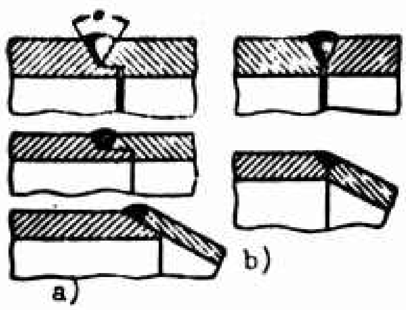


Fig. 10. Joints for automatic welding under flux of parts of small diameter.

During use of a melt mouthpiece welding is possible butt-to-butt and in T-connection of parts of variable thickness with double curvature of axis of joining.

Position of welded seam is vertical or slanted (at an angle to 30-40° to vertical), and also annular.

Contemporary methods of welding and, especially, electroslag welding, allow very effective replacement of heavy cast in block and seamless-forged parts with welded-poured, welded-forged or welded parts from separate castings, forgings and rollings. Welded-poured constructions are expedient for: a) impossibility of casting of part as a whole, in particular, from insufficient capacity of metallurgic furnaces and cranes of casting houses or overload of these workshops; b) essential simplification of casting of separate elements of construction, for instance, during dismemberment of a bulky space segment A-A of a stator of a powerful hydroturbine (Fig. 11a) into flat sections of rings 1 and 2 and columns 3, or replacement of a casting, molded manually, by two or more welded castings, allowing machine molding; c) use in construction along with high-alloy steel of cheaper construction steels in those places, where special properties of expensive material are not used (for instance, in a welded-poured operating wheel of a hydroturbine in Fig. 11b, working with erosional wear the flange 1 can be poured from low-alloy steels, but blade 2 and the lower rim 3, from high-alloy erosion-resistant steel); d) improvement of quality of section castings as compared to the quality of cast-in-block parts, for instance, in castings from certain austenitic steel;

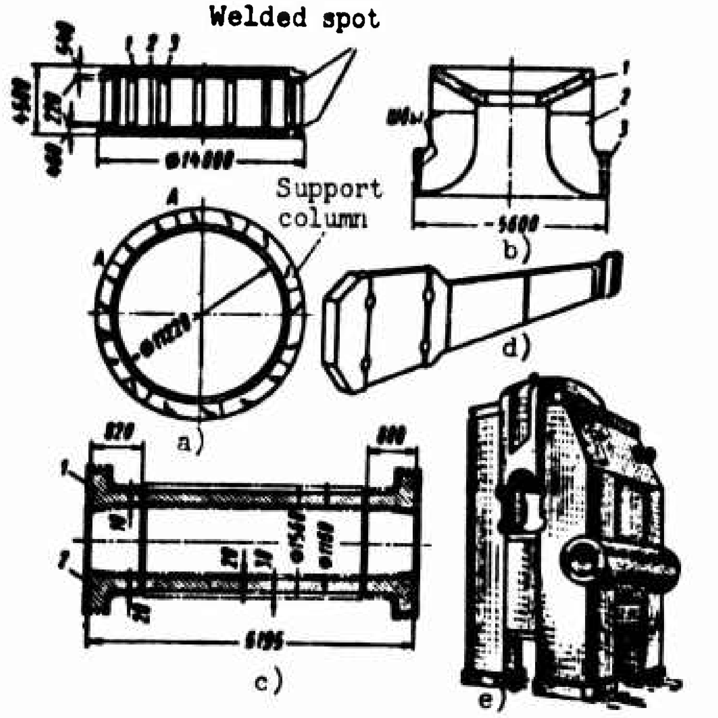


Fig. 11. Welded-poured, welded-forged and welded constructions: a) stator of hydroturbine; b) operating wheel of a hydroturbine; c) welded shaft; d) welded element of hydropress (weight near 95 m); e) welded bed of a crank press (weight near 90 m).

e) decrease of section of separate elements of a casting and, as result, decrease of weight of construction on the whole.

Application of welded-forged details is expedient: a) for decrease of load of individual forging and pressing equipment (for instance, during manufacture of a shaft of a powerful hydroturbine in Fig. 11c welded from forged pipe 1, obtained from a hollow ingot, and poured flanges 2; the load of the press 10,000 m is decreased by 6 times with simultaneous reduction of expenditure of liquid steels by 40% and reduction of cost of shaft blanks by 30%); b) for increase of quality of a part (in separate zones of big forged parts, the required forging is not always ensured).

Heavy parts from rolling and from rolling in combination with casting and forgings are most expediently welded in two cases; a) for obtaining of plane parts, the dimensions of which exceed normal dimensions of thick sheets (for instance, elements of presses welded from four parts, Fig. 11f); b) for creation of complicated space constructions of large weight and dimension and (for instance, the bed of a crank press, Fig. 11e).

Gas welding and arc welding in gases. During gas welding it is

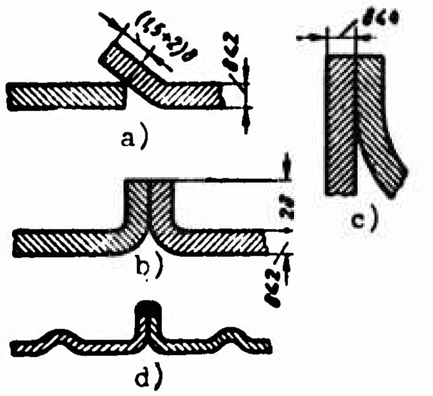


Fig. 12. Constructions of joints using gas welding.

better to execute the joint butt-to-butt and with flanging, ensuring identical heating and deformation of welded details. Flanging of one (Fig. 12a) or both details (Fig. 12b) is applied for $\delta \leq 2$ mm; joining with flanging (Fig. 12c) — for $\delta \leq 4$ mm; joining butt-to-butt without bevel of edges for $\delta \leq 5$ mm; joining butt-to-butt with V-shaped bevel — for $\delta \geq 5$ mm. Thin parts frequently are welded in T-connection. Parts from light alloys in advoidance of warping sometimes are processed in a creasing machine (Fig. 12d).

<u>During arc welding with a nonconsumable electrode with gas protection</u> joining butt-to-butt and with flanging is used, but on welding with a consumable electrode — also T-connection (see "Argon arc welding," p. 299).

<u>Contact joint welding and gaspress welding</u>. <u>Sections of parts</u> near the joint have to be identical for guarantee of identical heating of parts and identical plastic flow at the welding end (construction by Fig. 13a-c satisfy this requirement, in Fig. 13d-f they do not satisfy it). During contact welding depending upon the section of the part shortening of the part a = 8-50 mm (usually 10-20 mm), during gaspress welding a = 10-30 mm (for round details a ≈ 0.3 d). Deviations in dimensions of parts in avoidance of unequal heating do not have to exceed 15% in diameter of round rods and in thickness of wall of pipes, 10% for the side of a square rod. During

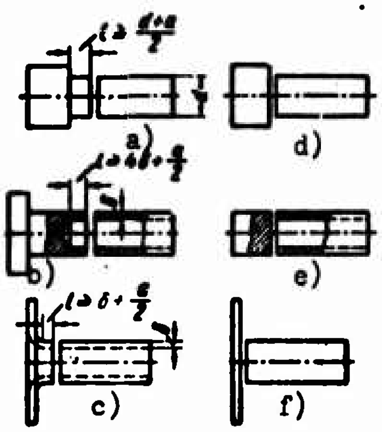


Fig. 13. Joining by butt-seam welding.

contact welding faces of parts are usually flat. During gaspress welding of tubes and also during contact welding of them by resistance with gas protection, bevel of edges is desirable with total opening outside respectively 20-40° and 12-14°; in the remaining cases bevelling is not accomplished.

Rings with ratio of internal diameter to diameter or thickness of blank greater than 10 can be welded with one joint; more rigid rings, for instance, links of chains in diameter greater than 20 mm are welded by contact joint welding from two semirings.

Spot welding. Size (diameter) of welded points is determined by the diameter of their internal nucleus, melted during heating. Its dimensions depend on the degree of heating, i.e., from parameters of the process. With corresponding selection of parameters and $\delta \geq 0.5$ mm the diameter of the welded point can be taken equal $d_m = 2\delta = 3$ mm, where δ is thickness of the thinner of the welded parts in mm.

Distribution of welded points (Table 2) is determined by the following: during setting of a number of points part of the electrical current is shunted through earlier welded points; the smaller the step of points, the bigger the degree of shunting and the less are the stable dimensions of the welded points. For small distance of the point from the edge of the part pressing of the heated metal at the edge, accompanied by deep squeezing of the part and lowering of

Table 2. Distribution of Points During Welding of Part from Construction Steels

Thickness of part in mm	Recommended minimum of step of points in mm		Minimum distance from center of point to ribs and flanges in mm
	During welding of two parts	During welding of three parts	
1	12	20	8
2	18	30	12
3	26	40	18
4	36	50	25
6	50	80	30

durability of the joint is accomplished. Obtaining of reliable contact between welded parts is hampered for distribution of points near the ribs and elements increasing local rigidity of the parts.

Construction of welded units should satisfy the following; a) mass of parts and attachments made of ferromagnetic material, introduced in contour of welding chain of the machine, should be as far as possible minimum; during shift of such parts in contour their resistance is changed along with current which leads to instability of results (constructions in Fig. 14a and b are less satisfactory than constructions in Fig. 14c); b) welded units during compression by electrodes do not have to be strongly deformed (welding of thin sheets with a thick-walled tube in Fig. 14d is possible, and with thin-walled in Fig. 14e with a diameter, not allowing introduction within copper mounting, is impossible); c) free deformation of details in the zone of the welded point should be ensured (joints in Fig. 14f completely satisfy this requirement);welding of joinings in Fig. 14g and i is hampered.

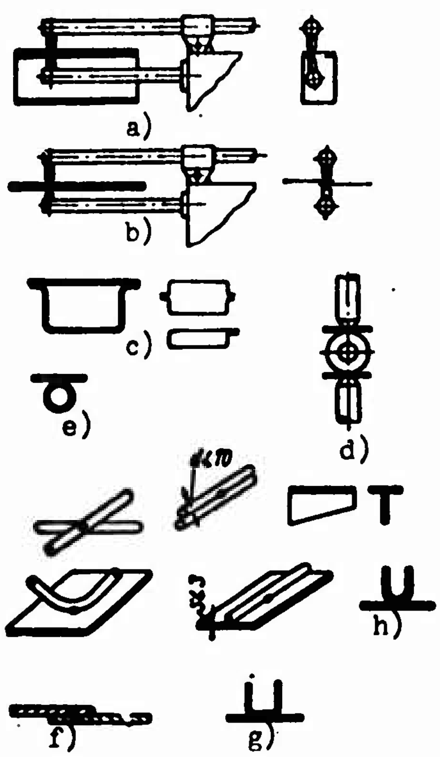
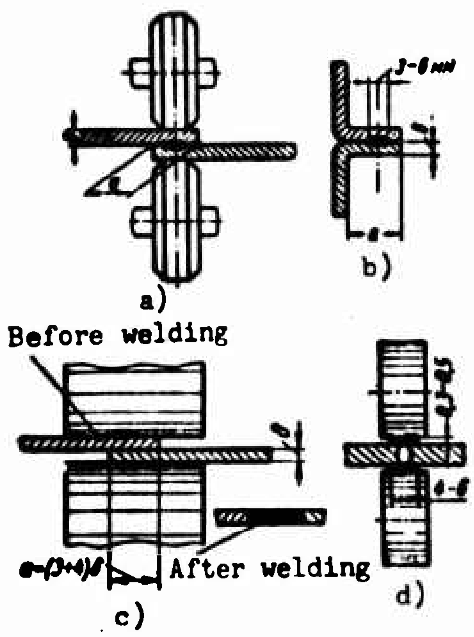


Fig. 14. Construction peculiarities of units with spot welding.

Roller welding. Types of joints are shown in Fig. 15 (a – overlapping and b – with flanging). Minimum dimension of overlap or flanging is the following:

Thickness of one sheet in mm	a in mm
0.25-0.5	10
0.75-1	12
1.5	15
2	18
3	20



•Fig. 15. Types of joinings during roller welding.

With decrease in overlap to (2-3) δ and wide electrodes (Fig. 15c) edges of the parts during welding are flattened to a thickness, close to δ. Deficiencies of this joint are lowered durability and significant wear of electrodes; its advantage is smooth surface of article, allowing qualitative finishing.

Durable joining with a smooth surface, allowing subsequent cold stamping is offered by roller welding butt-to-butt (Fig. 15d) with cover plates from foil in thickness 0.3-0.5 mm with a width of 4-5 mm. By this method it is possible to weld parts made of steel in thickness to 3-4 mm.

Relief and T-shaped welding. On relief welding in one of the welded parts flanges (dimensions of flanges see on p. 365) are stamped determining places of formation of welded points. The number n of simultaneously welded points (number of flanges) depends on the thickness of parts and on the capacity of the welding machine. Usually n = = 2-4, sometimes for thin details the number of points reaches 8-12. The minimum distance between flanges is 2.5D, from projection to the edge of the part, 2D (D is the diameter of the projection).

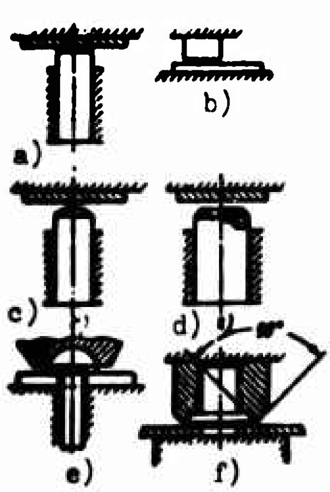


Fig. 16. Examples of T-shaped welding.

T-shape welding is used to join parts of sharply differing section (Fig. 16). For flat faces (Fig. 16a and b) it is not convenient to weld the entire section;

therefore on one of the parts can be stamped or mechanically processed flanges (Fig. 16b-d), localizing heating and welding where density of joining is required (welding of a stub pipe to the body of a tank in Fig. 16c) or its greatest durability (welding of pin and bolt in Fig. 16d and e).

The area of the welded joint during T-shaped welding usually does not exceed 100-150 mm^2 (area of contact of welded parts may be a few times larger).

ELECTRICAL WELDING BY FUSING

General Information

To electrical welding by fusing it is possible to relate manual arc welding by covered electrodes, welding under flux, electroslag welding, and also welding in protective gases.

Manual arc welding is universal and is the most versatile; automatic welding under flux is the most effective for manufacture of monotypic structures from metal of average thickness with long rectilinear (or circular) seams, which it is possible to execute the lower position in 1-2 passes from each side of the article. If the thickness of the articles is greater than 30-50 mm and the seams may be welded vertically, then one should apply the electroslag process. Welding in a medium of protective gases is used for joining of carbon low-alloy, low-alloy constructional, high-alloy rust-resistant aluminum, magnesium, nickel and copper alloys; active and rare metals (titanium, zirconium, tantalum, molybdenum). In the Soviet Union welding in argon and carbon dioxide is used; welding in steam is being developed (welding of defects of steel casting, welding of steel MSt.3 at a current of 200-250 a using wire Sv-0.8); welding of copper by a tungsten electrode with addition in a protective medium of nitrogen is done.

Steel welding wire by All-Union Government Standard 2246-60 usually is used for the manufacture of electrodes, and also for automated welding and hard-facing under flux in protective gases and for electroslag welding. The wire is released with a cold-drawn diameter of 0.3-12 mm (normal and heightened accuracy) in skeins by weight 1.5-40 kilograms.

As the standard is foreseen conditional designation of the wire. For instance, wire of steel Sv-08A in diameter 4 mm of heightened accuracy (P) is designated Wire 4 Sv-08AP All-Union Government Standard 2246-60 (in designation of wire of normal accuracy the index of accuracy is not indicated).

Sources of supply of welding current. Sources of supply of general assignment (Table 3) are subdivided into: a) machines or apparatuses of constant and alternating current (with incident, rigid and increasing characteristics); b) mono- and multiguard; c) mobile and stationary; d) universal for manual or automated welding (under flux, in gases, electroslag) and e) with electric motor (variable or direct current) and internal-combustion engine.

In the USSR chiefly is wide-spread welding on alternating current. Welding on direct current is applied in those cases where it is impossible to carry out welding on alternating current or it does not satisfy by presented process the requirements. Direct current is used usually for welding under field conditions, welding in gases by consumable electrode, and also during welding of special steel, metal of small thickness and automatic welding of responsible articles during fluctuation of voltage in the electrical circuit. However inclusion of an oscillator in the welding chain allows in a number of cases the use of alternating current.

Table 3. Sources of Supply of Welding Current (General Assignment)

Type	Capacity*[1]	Current welding in a	Basic assignment	Execution
Transformers				
STE-24 STE-34	24 34	70-500 150-700	For manual welding	Two-body (separate reactor), with incident characteristics, mobile
TS-300*[2] TS-500	20 32	110-385 165-650		Monobody (with mobile winding) with incident characteristics, mobile
STN-350 STN-500	25 33	80-450 150-700		Monobody (reactor on general magnetic circuit) with incident characteristics, mobile
TSD-500 TSD-1000-3 TSD-2000-2	32 76 180	200-600 400-1200 800-2200	For automated welding under flux	Monobody with incident characteristics and remote adjustment, mobile
TShS-1000 × 3*[3] TShS-3000 × 3	160 450	300-900 300-3000	For electro-slag welding	Monobody with rigid characteristics and remote adjustment, three-phase
Rectifiers				
VS-200 VS-400	— —	30-200 50-400	For automated welding in carbon dioxide	Monobody, with rigid characteristics, mobile
VSS-120-4 VSS-300-2	8.6 13.5	15-130 40-300	For manual welding	Monobody, with incident characteristics, mobile
VSK-300	—	75-400	Universal (for manual and automated welding in protective gases and under flux)	Monobody, with sloping characteristic, mobile
VSU-300	—	50-320*[4] 25-240		Monobody, with rigid and incident characteristics, mobile

*[1]Capacity, consumed by transformers and rectifiers, is shown in kilovolt-amperes; capacity of converters and assemblies pertains to their motors and is indicated for electric motors in kilowatts, and for internal-combustion engines in horsepower.

*[2]Transformers of type TS with built-in capacitors (for increase of coefficient of capacity) are marked TSK-300 and TSK-500.

*[3]May be switched to single-phase load up to 2000 a.

*[4]Upper figures correspond to current for inclusion of rigid characteristics, lower — incident.

Table 3 (Continued)

Type	Capacity*1	Current welding in a	Basic assignment	Execution
			Converters	
PSO-120	4	30-120	For manual and automated welding	Monobody, with incident characteristics, mobile
PSO-300	14	75-320	For manual and automated welding	
PSO-500	28	120-500		
PS-300M	14	80-380		
PS-500	28	120-600		
PSG-500	28	50-500	For automated welding in protective gases	Monobody, with rigid characteristics, mobile
PSU-500	28	50-500*4 120-500	Universal (for manual and automated welding in protective gases and under flux)	Monobody, with rigid and incident characteristics, mobile
PSM-1000	75	(10-200)·9	For manual welding on 9 posts	Monobody, with ballast rheostats for obtaining of incident characteristics, stationary
			Assemblies with electric motors	
SAM-400	32	120-600	For manual welding under conditions of heightened humidity	Two-machine (motor of variable or direct current*5 with incident characteristics, stationary
ASO-2000	115	300-2400	For automatic welding under flux (in pipe-welding production)	Three-machine (motor with two generators SG-1000-1) with incident characteristics stationary
			Assemblies with internal-combustion engines	
ASB-300-2	30	75-320	For arc welding under field conditions	Two-body (generator and gasoline motor on general frame), with incident characteristics, stationary (transport)
ASD-3-1	60	120-600		Two-body (generator and diesel engine on general frame) with incident characteristics, stationary (transport)

*5For a motor of direct current the unit is marked SAM-400-1. Other units given in the table with electric motors, and also converters, have alternating current motors.

Table 3 (Continued)

Type	Capacity*[1]	Current welding in a	Basic assignment	Execution
ASDP-500G	60	(100 to 350)·2	For arc welding under field conditions on two posts	Two-body (generator and diesel engine are mounted in trailer), with ballast rheostats for obtaining of incident characteristics
PAS-1000*[6]	150	300-1200	For auto-welding under field conditions	Two-machine generator with diesel engine frame) with incident characteristics

*[6]Generator ST-1000-1 from unit PAS-1000, mounted jointly with an alternating current motor is used as a stationary unit during automatic welding.

Manual Arc Welding by Covered Electrodes

Melting of welded metal is usually 1-3 mm. Therefore during manual welding, seams (especially multilayer) almost completely will be formed at the expense of electrode metal. Technical requirements for preparation of edges, assembly of joinings and forming of seams are regulated by All-Union Government Standard 5264-58.

Electrodes. Basic requirements for melted electrodes are regulated by All-Union Government Standand 9466-60, 9467-60, 10051-62 and 10052-62.

All-Union Government Standard 9466-60 establishes the following (respectively) dimensions of electrodes (in mm):

Diameter of rod	1.6-12
Length of electrode	250-450
Permissible difference of thickness of covering (double eccentricity)	0.05-0.30

The most wide-spread electrodes in diameter 4 and 5 mm, length 400-450 mm. In GOST 9466-60 are given the technical requirements and methods of test of electrodes content of log book on electrodes and also condition of marking, packing, transportation and storage of electrodes.

Every type of electrodes by GOST 9467-60 (Table 4 and 5) can correspond to one or several brands. Conditional designation of electrodes includes brand, type and diameter of electrodes, form of covering (ore-acid – R, rutile – T, fluoride-calcium – F, organic – O) and number of GOST. For instance: TsM7-E42-5,0-R GOST 9467-60.

Table 4. Types of Electrodes for Welding of Construction Steel and Basic Norms (By GOST 9467-60)

Types of electrodes	Mechanical properties of metal of seam or fused metal during application of electrodes of diameter greater than 2.5 mm			Mechanical properties of welded joint during application of electrodes in diameter 2.5 mm		Content in metal of seam or fused metal		Welded steel
	Temporary resistance to breaking in kg/mm^2	Elongation per unit length δ_5 in %	Shock viscosity in kg·m/mm^2	Temporary resistance to break in kg/mm^2	Angle of bend in degrees	Sulfurs	Phosphorus	
	Not less					In %, not more		
E34	34	-	-	34	30	0.05	0.05	Low-carbon and low-alloy
E42	42	18	8	42	120	0.05	0.05	
E42A	42	22	14	42	180	0.04	0.04	
E46	46	18	8	46	120	0.05	0.05	
E46A	46	22	14	46	150	0.04	0.04	
E50	50	16	6	50	90	0.05	0.05	Average carbon and low-alloy
E50A	50	20	13	50	150	0.04	0.04	
E55	55	20	12	55	140	0.04	0.04	
E60	60	16	6	-	-			Alloy heightened durability
E60A	60	18	10	-	-			
E70	70	12	6	-	-			
E85	85	12	5	-	-	0.04	0.04	
E100	100	10	5	-	-			
E125	125	6	4	-	-			
E145	145	5	4	-	-			

Table 5. Types of Electrodes for Welding Heat-Resistant Steel and Basic Norms (By GOST 9467-60)

Type of electrodes	Property of metal of seam or fused metal											
	Mechanical properties in 20°C			Chemical composition in %								
	Temporary resistance to break in kg/mm²	Elongation per unit length δ in %	Impact ductility in kg·m/cm²	C	Si	Mn	Cr	Mo	Va	Nb	S	P
	Not less										Not more	
E-M	50	18	8	0.06—0.12	Not over 0.35	0.4—0.8	—	0.40—0.70	—	—	0.05	0.05
E-MKh	50	18	8	0.06—0.12	Not over 0.35	0.4—0.8	0.3—0.6	0.40—0.70	—	—	0.04	0.04
E-KhM	50	16	8	0.06—0.12	0.15—0.45	0.5—0.9	0.7—1.0	0.40—0.70	—	—	0.04	0.04
E-KhMF	50	16	8	0.08—0.13	0.15—0.45	0.5—0.9	0.8—1.2	0.40—0.70	0.10—0.35	—	0.04	0.04
E-KhMFB	55	14	6	0.08—0.13	0.15—0.45	0.5—0.9	1.0—1.4	0.70—1.00	0.15—0.40	0.10—0.25	0.04	0.04
E-Kh2MFP	55	14	6	0.08—0.13	0.15—0.45	0.5—0.9	2.4—3.0	0.70—1.00	0.25—0.50	0.35—0.65	0.04	0.04
E-Kh5MF	55	14	6	0.08—0.13	0.15—0.45	0.5—0.9	4.5—5.0	0.40—0.70	0.10—0.35	—	0.04	0.04

Note: Norms of mechanical properties are shown after heat treatment in conformity with log book on electrodes.

Selection of brand of electrode for welding or responsible objects most basically may be done according to log books or special brands on electrodes. In Table 6 are given for orientation during selection, certain brands of electrodes.

Optimum conditions of weldings mechanical properties of seams, and also other data are given most fully in log books of electrodes.

Electrodes of diameter 3 mm and higher than the majority of brands for carbon and low-alloy steel allow welding in the lower position on current, which it is possible to calculate by the formula $I = 40d$, where I is the current in a, d is the diameter of rod of electrode in mm. Current during welding in vertical and ceiling positions is lowered (with respect to that calculated by the formula) respectively on the average by 10 and 20%; electrodes by diameter more than 4 mm for these operations, as a rule, do not apply. Welding in the lower position by electrodes of brand TsM-7S is produced on heightened current (1.6-1.[illegible] times). Applying for corresponding

works electrodes of this brand of diameter 6-8 mm it is possible to increase productivity of welding a few times as compared to welding by electrodes OMM-5 of diameter 5 mm which is caused not only by increase of welding current but also a large coefficient of hard-facing, equal for them on the average to 12 g/a·hr (against 8 g/a·hr for electrodes OMM-5). The transition of metal of a rod into a seam for electrodes TsM-7 (85-90%) and TsM-7S (90-95%) is also higher than for electrodes OMM-5 (80-85%). High-speed welding by electrodes TsM-7S of angular butt joints by the method of support, besides high productivity (to 30 m seam per hour), ensures deeper penetration. The heightened coefficient of hard-facing also is had by electrodes ANO-1, OZS-3 and others, containing in covering iron powder.

Table 6. Electrodes with Thick Covering for Arc Welding and Hard-Facing of Carbon and Alloy Steels

Brand of electrode	Type of electrode by GOST	Field of application		
		Brand of welded steels	Character of welded construction	Kind of current and polarity
OMA-2* TsM-7** TsM-9*** OMM-5	E42	Low carbon	Thin-walled constructions	Variable or constant
UONI-13/45	E42A	Low-carbon and low-alloy	Responsible constructions, working with application of static dynamic loads at heightened and lowered temperatures	Constant reverse polarity; variable — with oscillator
UONI-13/55 UONI-13/65	E50A E60	Average-carbon and alloy		
TsL-18 TsL-19	E-85 E-100	Alloy type 20KhGSL, 15KhGSA and 30KhGSA		Constant — reverse polarity

*For electrodes OMA-2 is recommended current: with a diameter 1.6 mm, 16-25 a; 2 mm, 25-45 a; 3 mm, 50-80 a.

**Electrodes TsM-7 for heightened thickness of covering are marked TsM-7S. Electrodes TsM-7S allow realization of high-speed manual welding of joint and angle seams of low-carbon steels in lower position.

***Electrodes TsM-9 differ (just as ANO-1) by lowered separation of harmful gases and dust during welding.

Table 6 (Continued)

Brand of electrode	Type of electrode by GOST	Field of application: Brand of welded steels	Field of application: Character of welded construction	Field of application: Kind of current and polarity
TsL-6 TsL-11 TsL-20	E-M E-MKh E-KhMF	15M and 20M 12MKh 12Kh1MF, 20KhMF	Steam pipe-lines, collectors, boilers and turbines, working at a temperature respectively to 510, 521 and 540°	Variable
TsL-11	EA-1B	Stainless type 1Kh18N9T		
UONI-13/nzh	~EA-1a	Stainless, chrome-nickel 1Kh18N9 and 1Kh18N9T and chromous 1Kh1 and 2Kh13	Responsible constructions, working inan aggressive medium	
ENTU-3		Stainless 1Kh18N9 and 1Kh18N9T		
TsT-1		Heat-resisting austenitic type 1Kh14N14V2M and others	Responsible constructions, working at a temperature respectively to 660 and 660°	Constant — reverse polarity
Tst-15	~EA-1Ba	The same, type 1Kh18N12T		
TsI-1M	EN80V18Kh4F-60	—	Hard-facing of cutting tool and dies	
TsN-6	EN08Kh17N7S5G2-30	—	Hard-facing of dense surfaces of a pair of armatures, working at a temperature to 600°	
OZN-300 OZN-350 OZN-400	EN-15G3-25 EN-18G4-35 EN-20G4-40	—	Hard-facing on a part of wear-resistant layer of hardness respectively NV 300-400	

In the absence of electrodes of large diameter (6-8 mm) welding by a bundle of electrodes also promotes increase of productivity of labor. For welding of compact sections (for instance, joint of reinforcement in diameter 20-60 mm) "bath" welding by one electrode or a "distributing block" of electrodes is very effective. During correction of defects in a steel casting the method of welding by a three-phase arc by coupled electrodes is useful. Use of holders, to which the face of the electrode is lightly welded allows conduct of welding without cinders saving up to 10% of the electrodes necessary in the case of use of usual holders, pressing the end of the electrode by length 30-35 mm.

Welding of steel and cast iron. Best to weld is low-carbon steel; fully satisfactory are certain low-alloy construction steels (14KhGS, 19G, 10KhSND, 15KhSND, 09G2 and others), satisfactory, average alloy steels 20KhGS and 25KhGS. An increase in content of carbon and alloy elements in construction steels, and also an increase in thickness of metal and rigidity of joining evoke necessity to take during welding special measures (preliminary and accompanying heating to 100-300°, subsequent heat treatment, welding "by ridge" and "cascade" and others).

Difficulty is presented in welding of austenitic rust-resistant, acid-resistant and heat-resisting steels. Selection of brand of electrode and technology of welding of these steels should be done taking into account all conditions of operation of the welded joints. Electrodes of certain brands for welding of austenitic steel ensure content in the seam of a ferrite phase (near 5%) that prevents appearance of hot cracks. Lowered content of ferrite phase cannot prevent formation of cracks, but heightened – causing embrittlement of the

fused metal during heating to 350-850°. Content in the seams of ferrite phase may be controlled by a magnetic instrument - ferritemeter (type FVD or FTs-2) or (less exactly) the metallographic method. Inasmuch as chemical composition of an austenitic seam of specially responsible articles should exactly correspond to that given, and austenitic wire by GOST 2246-60 has enough wide limits of content of separate elements, composition of covering of electrode (for instance, brand TsL-11) is recounted in accordance with the chemical analysis of every specific melt.

It is recommended to weld austenitic steel at a somewhat lowered current (by 10-20% lower than that calculated by the formula $I = 40\ d$), with a short arc during reverse polarity by shafts of small section with a minimum of melting of basic metal. Craters must be melted with frequent short circuits, not carrying them in basic metal beyond the limits of the seam.

Good results during welding without preheating of parts from gray and highly durable cast iron, and also during welding of them with steel parts are given by use of steel electrodes of brand TsCh-4, ensuring equal-durability of welded joint, light machining of it, density and cleanness of surface. During welding of big defects or welding of large divisions of thick metal the welded edges are preliminarily faced by electrodes TsCh-4 in two layer, covering every subsequent shaft to 2/3 the width of the preceding. Welding of facing layer is done at low current, in small sections, not allowing heating of basic metal higher than 100°. The remaining volume of the division is then fused using electrodes of type E42A or with the help of semiautomatic welding in carbon dioxide. For welding of cast iron also electrodes made nonferrous metals (OZCh-1, TsCh-3A and others) are used.

For the purpose of increase of productivity of labor during manual welding it is necessary to apply tilters, manipulators, rotators (see Table 16) and other devices for mechanization of installation of article in the most favorable position for welding of different seams.

Automatic Welding Under Flux

Most widely applied is monoarc automatic welding under flux by solid wire of diameter 3-5 mm in the lower position. For semi-automatic welding usually wire is used of diameter 1.6-2 mm. Electrode rods (sections of wire of length 400-600 mm) are convenient during welding by electrorivets, scalding of connections and in certain other cases. For hard-facing both solid and powder (with alloyed ferro-alloys) wire and tape find application (giving a wide layer with little melting).

Automatic welding with compulsory forming of seam is used limited mainly during fulfillment of vertical seams to direct current (joint seams on metal of thickness 15-20 mm are welded on a current of 600 a, corner roll 4-8 mm, at a current of 200 a).

Welding with a "split" electrode (two electrodes in parallel connected to one pole of a general source feeding) and welding by three-phase arc (burning between two electrodes and the article in a common bath) are used for the necessity of adjustment of depth of melting of basic metal. Two- and three-arc welding in a common bath is used for increase of speed of process, but in separate baths — for multilayer seams. Using existing methods, it is possible to weld under flux different steel and nonferrous metals both small and large in thickness.

Flux is used not only for welding with a "closed" arc. With the help of magnetic flux (attracted to the end of the electrode under current) semiautomatic welding is carried out by open arc; aluminum is welded by half-open arc on a layer of flux.

Basic materials. Properties of metal with a welded seam are determined chiefly by composition of materials used: basic welded metal, electrode wire and flux. If the flux insignificantly reacts with these or other elements of the melting pool, the content of the latter in the metal of the seam may be approximately calculated by the formula $x = 0.65\ x_0 + 0.35\ x_\Pi$, where x, x_0 and x_Π are content of element x in % respectively in the metal of the seam, basic metal and electrode wire.

For welding under flux an electrode wire by GOST 2246-60 (Table 7) is used chiefly.

Industrial fluxes are made of melted and granulated silicates with dimension of particles 0.25-3 mm. Depending upon the method and conditions of granulation part of the flux can be glass-like (filled weight greater than 1.2-13 kg/∂m^3) or pumice-like (filled weight less than 0.9 kg/∂m^3). The former better insulate the melting pool from air, the latter give smoother outline of seam. Mixtures of them are also used.

For certain cases of welding (alloy steel, insufficiently pure metal) unfused (ceramic) fluxes KS-2 (for low-carbon steels), K-4 (for cold-resistant forging), K-7 (for highly durable steels), FKZh-4 (increasing coefficient of hard-facing), FTsK (allowing regulation of chemical composition of metal of seam in steel 1Kh18N9T for the purpose of guarantee of ferrite phase, and also stability against intercrystallite corrosion) and others, can be used.

Table 7. The Electrode Wire of Steel of Certain Brands (By GOST 2246-60)

Brand of electrode wire*	Basic assignment
Sv-08	Welding of low-carbon and low-alloy steel of certain brands under high-manganous fluxes of type OSTs-45 and AN-348A
Sv-08A Sv-08GA	The same, especially is recommended for welding of tee joints, and also for a content in the basic metal of sulfur and phosphorus at the upper limit
Sv-10GA Sv-10G2	Welding of carbon and low-alloy steels of heightened durability
Sv-08GS Sv-12GS	Welding of carbon steel for a speed of process over 100 m/hr, and also low-alloy steels of heightened durability
Sv-18KhMA	Welding of steel 20KhMA, 30KhMA
Sv-18KhGSA	Welding of steel 20KhGSA and 30KhGSA
Sv-10NM	Welding of boiler steels 16GNM
Sv-06Kh19N9T	Welding of steel 1Kh18N9T (during application of flux FTsK, ensuring mechanical and anticorrosive properties of welded joints)
Sv-10KhM and Sv-10MKh; Sv-08KhMFB Sv-08KhZMFB	Welding of low-alloy heat resisting steel of corresponding brands

*Besides those given in the table, possibly other electrode wires by GOST 2246-60 may be used for welding under flux of alloy steel of different brands.

During welding the flux insulates the melted metal from the influence of atmospheric air; metallurgically it interacts and forms the surface of the seam.

Mean values of necessary thickness of layer of flux above the welded bath and protrusion of electrode from the current distributing

sponges of the welding head approximately are equal to 10-12 diameters of the electrode wire. Expenditure of flux approximately corresponds to expenditure of electrode wire.

For fluxes AN348A and OSTs-45 supplied in centralized order, exists GOST 9087-59.

Fluxes OSTs-45 and AN348A are used for welding of joints of almost all forms (besides annular seams of small diameter in vertical plane) from carbon steel. Besides indicated fluxes of two brands, also others are used, in particular flux FTs-7, for multipassage welding by three-phase arc, and also for electroslag welding. Flux FTs-9 possesses best (as compared to other fluxes) hygienic properties and is recommended therefore for semiautomatic welding.

Conditions and forms of joints. Welding current, diameter of electrode, voltage of arc and speed of welding are basic parameters of welding condition (Table 8). Furthermore, form and quality of welded seam depend on composition, state and granulation of flux, slope of electrode and article, construction of welded joints and other factors.

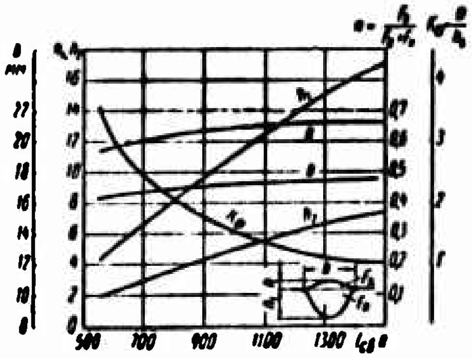
In Fig. 17 is shown the influence of a welding current on the depth of melting h_1, strengthening h_2 width b and form factor of seam $K_ф$, and also on the fraction of participation of basic metal in welded seam n. These regularities, obtained for hard-facing, with known approximation can be wide-spread to joint and corner seams.

During automatic welding under flux basically the same types of welded joints are used (joint, corner, overlap and others) as during manual welding. Constructive elements of basic types of seams of welded joints from carbon and low-alloy steel, executed by automatic or semiautomatic welding under flux, are regulated by GOST 8713-58.

Table 8. Influence of Conditions of Welding Under Flux on Form of Seam

Characteristic of seam	Change of characteristic of seam with increase						
	Welding current	Diameter of electrode	Voltage of arc	Speed of welding	Angle of inclination of electrode to vertical*	Angle of inclination of article during welding	
						On descent	On rise
Depth of penetration	Intensely is increased	Decreases	Almost does not change	Somewhat decreases	Intensely decreases	Decreases	Increases somewhat
Width of penetration	Increases somewhat	Is increased	Is increased	Decreases	Is increased	Is increased	Somewhat decreases
Height of strengthening	Intensely is increased	Decreases	Decreases	Is increased	Decreases	Decreases	Is increased
Form factor	Intensely decreases	Is increased	Is increased	Somewhat decreases	Intensely is increased	Is increased	Decreases

*During welding "by angle forward."



.Fig. 17. Influence of current on form of seam and share of basic metal in it during hard-facing of shafts under flux (diameter of electrode 5 mm, speed of hard-facing 40 m/hr, voltage of arc 36-38 v, flux OSTs-45

Certain specific peculiarities of the process of welding under flux (deep penetration, fluidity of metal of welded bath and others), requiring special measures opposite to the flow of liquid metal through the gaps of the joints at the same time give the possibility of executing shapes of joints inaccessible to manual welding (joining by cut seams, electrorivet and others). For preventing of flow of liquid metal through looseness of joint the following methods of automatic welding of joint seams are used: welding by manual or automatic auxiliary welding, on flux, copper or remaining steel lining.

For monotypic welding of corner seams thanks to deep penetration, calculating the dimension of seam may be taken equal to the dimension of its leg. Thus, the durability of seam, carried out under flux, is approximately 40% higher than durability of seam of the same leg during manual welding. For obtaining equidurable corner seams during manual welding it is necessary to fuse approximately twice more electrode metal than during automatic monotypic welding. Deep melting allows instead of bilateral corner seams of tee joints the use of (when this is founded by calculation) one-sided corner seams. Intermittent corner seams in a number of cases are replaced by "point" seams, welded hose semiautomatic machines at a current of 160-200 a, (productivity—30-40 points per minute). Deep melting allows also welding by electrorivets in the absence of a hole in the upper part of the metal of thickness to 8 mm (welding current to 2000 a, supply

of electrode in diameter 6-50 mm). Welding by an electroclamp with a thickness of upper sheet of 1-2 mm can be executed without supply of an electrode in diameter 5-6 mm on current respectively 600-1000 a.

Automated welding of corner seams of tee joints can be executed at the horizontal (lower) position of one of the welded sheets and slanted (in "boat"). In the first case the electrode usually is located at an angle of 45-60° to the horizontal sheet, in the second, vertically. Welding in the lower position of one of the welded sheets simplifies construction of stands and reduces expenditure of time on edging of articles, single-pass welding of corner joints in the lower position gives the possibility of having seams with dimension of roll to 10 mm. For welding in position of "boat" the roll of the seam practically is not limited.

Conditions of welding under flux are developed for the most varied conditions. Selection of conditions for a specific article should be confirmed by welding of the development type. For orientation during selection of conditions it is possible to use Tables 9-13.

Table 9. Conditions of Bilateral Automatic Welding Under Flux of Butt Joints with Obligatory Gap.

Thickness of sheets in mm	Width of gap end to end in mm	Diameter of electrode in mm	Welding current in a	Voltage of arc in volts	Speed of welding in m/hr
14	3-4	5	700-750	34-36	30
16	3-4		700-750	34-36	27
18	4-5		750-800	36-40	27
20	4-5		850-900	36-40	27
24	4-5	6	900-950	38-42	25
28	5-6		900-950	38-42	20
30	6-7		950-1000	40-44	16
40	8-9		1100-1200	40-44	12
50	10-11		1200-1300	44-48	10

Table 10. Conditions* of Monotypic Automatic Welding Under Flux of Tee Joints "in Boat."

Roll of seam in mm	Welding current in a	Speed of welding in m/hr
6	600-700	40
8	700-750	25
10	750-800	18
12	850-900	15
14	850-900	10

*Diameter of electrode 5 mm, voltage of arc 34-36 v.

Table 11. Conditions of Automatic Welding Under Flux of Corner Seams in the Lower Position Using a Slanted (45°) Electrode

Roll of seam in mm	Diameter of electrode in mm	Welding current in a	Tension of arc in volts	Displacement of electrode from a vertical sheet in mm	Speed of welding in [illegible]
6	4	600	30	1.5	55
8	5	700	32	2.5	40

Table 12. Condition* of Bilateral Semiautomatic Welding of Joint Seams (on a Flux Pad)

Thickness of sheets in mm	Current in a	Voltage of arc in volts	Rate of supply of wire in m/hr
4	220-240	32-34	101
5	275-300	32-34	156
8	450-470	34-36	306
12	500-550	36-40	378

*Diameter of electrode is 2 mm, speed of welding 18-24 m/hr.

Table 13. Regimes* Semiautomatic Welding Under Flux of Corner Seams

Roll of seam in mm	Current in a	Voltage of arc in volts	Speed of supply of wire in m/hr	Speed of welding in m/hr
4	220-240	32-34	101	24-30
5	275-300	32-34	156	24-30
8	380-420	34-38	250	18-24

*Diameter of electrode 2 mm.

Table 14. Influence of Heat Treatment on Mechanical Properties of Metal of a Seam Welded Under Flux on Steel MSt. 3

Form of heat treatment	Temporary resistance to break in kg/mm^2	Yield point in kg/mm^2	Elongation per unit length in %	Relative narrowing in %	Shock viscosity in $kg \cdot m/cm^2$
Without heat treatment	46.3	31.4	25.5	64.2	10.5
Tempering at 650°.....	43.6	25.7	33.1	69.9	12.5
Annealing at 930°.....	39.6	23.0	35.3	71.5	13.4
Normalization at 930°	38.2	24.0	35.3	71.2	15.7
Hardening at 930°.....	54.4	34.9	24.4	—	8.0

Note: Metal of a seam of optimum chemical composition — to 0.10-0.13% C; 0.15-0.30% Si; 0.65-0.90% Mn; to 0.03% S; to 0.03% P.

Table 15. Mechanical Properties (Average) of Seams, Welded Under Flux on Certain Steels

Brand of welded steel	Temporary resistance to break in kg/cm^2	Yield point in kg/cm^2	Elongation per unit length in %	Relative narrowing in %	Shock viscosity in $kg \cdot m/cm^2$	Note
MSt. 4	51.5	35.8	28.2	64.1	8.7	Thickness of metal 14 mm. Flux OSTs-45 and low-carbon wire. Without heat treatment
15M*	55.4 56.4 49.5	40.2 33.0 34.1	22.0 21.8 19.6	70.7 53.6 56.3	10.8 13.3 7.4	Multipassage welding. Flux OSTs-45A and wire 15M. Tempering at 650-680°C
NL-2	62.9	42.2	22.2	55.8	9.3	—
30KhGSA	102.5	92.1	15.5	52.5	3.95	Flux OSTs-45 and wire 20KhMA. Hardening and tempering
30KhGSNA	112.9	—	9.7	50.5	9.9	Flux FTsK-M and wire 15KhGSNA. Hardening and tempering

*Mechanical properties of seams are given for temperature of test respectively of 20°, 350° and 510°C.

In addition to low-carbon steels, on automatic machines and semiautomatic machines also copper, aluminum and their alloys are welded. Condition of welding of low-alloy steels are close to condition of welding of low-carbon steels.

Automatic hard-facing under flux found the widest application during restoration of geometric form of rollers, tires of wheels, tractor rolls, cutting and boring tools and several other details. Hard-facing now is still insufficiently used for creation of surfaces with special official properties during factory manufacture of corresponding parts. For attaching to fused surfaces of special properties is used, as a rule, corresponding alloy electrode material (solid and powder wire and strip). In order to decrease dilution of a fused layer by basic metal, it is recommended to select methods and condition, ensuring minimum depth of melting (welding along a wide strip, welding during prolongated "departure" of the electrode, multielectrode welding "by comb," welding by three-phase arc and others). Semiautomatic hard-facing under flux most frequently is applied during removal of defects of a steel casting.

The properties of seams, welded under flux in low-carbon steels, and also in alloy steels of a number of brands during selection of regular technology, as a rule, correspond to requirements of technical conditions in basic metal or close to it (Table 14 and 15).

Equipment and apparatus (Table 16). An installation for automatic welding consists basically of a source of power supply, welding equipment and mechanisms, united by electrical circuit and working in a given technological sequence. In Fig. 18 is shown a constructive circuit of installation for automatic welding of longitudinal and annular seams of cylindrical articles. Seams inside an article are

welded by a tractor (in the figure it is not shown). In a number of cases it is expedient to use tractors in an installation for welding of external seams.

Table 16. Equipment and Apparatus for Automated Welding Under Flux

Apparatus and equipment	Basic assignment
Suspension welding heads: light type (from an automatic machine ADS-500 construction by the factory "Electrician," or A-580 construction IES); average type (from tractor UT-1250-3 construction TsNIITMASh or automatic machine of ADS-1000-2 construction of factory "Electrician"); heavy type (head A or AB from apparatus ABS of construction IES); heavy type (head L with follow-up system for continuous work, construction TsNIITMASh); two-electrode (type TGTs-2 construction TsNIITMASh); two-electrode (type A-288 of construction IES).	Assembly of autowelding installations
Welding tractors with combined welding head and carriage: automatic machine ASU-138 for one-sided and automatic machine DASU-138 for two-sided welding of corner seams; tractor DTS-24 for welding by two consecutive arcs (construction IES); tractor of type TS-17M for butt and corner seams (construction IES); tractor of type TS-32 for welding on a travelling copper lining (construction IES); tractor of type TS-26 for welding of annular seams inside articles with diameter larger than 1200 mm without division of edges (construction IES); self-propelled welding head of type SSG-3 for annular seams inside cylindrical articles with diameter larger than 800 mm (construction TsNIITMASh)	As transportable apparatus and for assembling autowelding installations

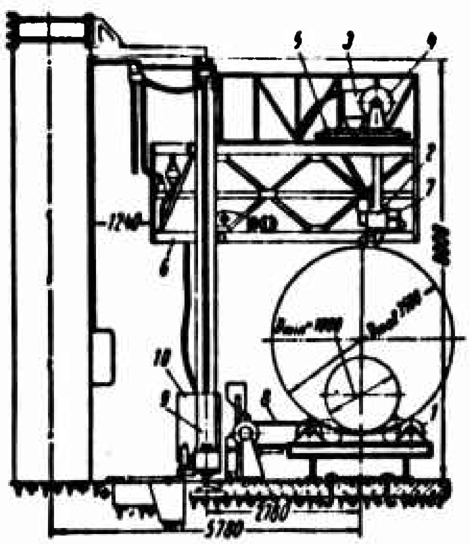
Table 16 (Continued)

Apparatus and equipment	Basic assignment
Welding machines for closed (annular, oval) seams: automatic machine of type ADSK-1000 for welding of rims of automobile wheels; automatic machine of type ADK-500 for welding of fla[illegible]s;* automatic machine of type ADN-500 for hard-facing of fittings;* automatic machine of type ADTR-300 for scalding of tubes;* automatic machine ADOB-300 for welding of oval bottoms;* machine R-837 for hard-facing of shafts with diameter 740-860 mm (construction IES)	Welding — in serial and mass production; float — usually during repair works
Welding machines for rectilinear seams: installation of type ADTsP-300 for welding of longitudinal seams of cylindrical articles (construction VNIIESO); assembly-welding; automatic machine type STS-1 for manufacture of tee profiles; welding-milling machine for butt-joining of bands (with simultaneous removal of strengthening of seam) on pipe-welding machines "650" and "720" (construction TsNIITMASh and and Minsk machine-tool plant)	Serial and mass production
Universal welding tractors with separate welding head and carriage: welding tractors of type UT (UT-1250-2, UT-1250-3, UT-1500, UT-2000M construction TsNIITMASh); welding automatic machines of type of ADS-500 and ADF-500 (construction of factory "Electrician"). Welding automatic machine ADSD-500 (two-electrode, construction of factory "Electrician;" welding automatic machine of type of ADS-1000-2, three-phase automatic machine of type ADST-1000. Two-electrode automatic machine of type ADSD-1000 (construction of factory "Electrician") *Construction VNIIESO	As transportable apparatus and for assembling auto-welding installations

Table 16 (Continued)

Apparatus and equipment	Basic assignment
Self-propelled apparatuses, moving on directing rails, located above the welded article: unified welding head of type ABS. Self-propelled head of type SAG-4-U (construction IES); self-propelled welding head TS-17-S (modified tractor TS-17-M construction IES); modified tractor type UT with welding head, mounted under carriage (construction TsNIITMASh)	Assembly of autowelding installations
Special apparatuses: type AOS for scalding of connections and type AOSh for scalding of carbines (construction TsNIITMASh); for welding of pins (construction VNIIESO, IES and others). For welding by electrorivets (construction NIIdormash, VISKhOM and others); type A-433-M for welding of vertical seams (construction IES)	For serial and mass production. Apparatus A-433-M for welding of bridge and other constructions on assembling
Hose equipment: semiautomatic machines of types PSh-5, PSh-54 and three-electrode semiautomatic machine A-420 (construction IES); semiautomatic machines of types PDSh-500 and PDShM-500 (construction of factory "Electrician"); automatic machines of types ADSh-500 and ADShM-500 (construction of factory "Electrician")	For use under conditions, requiring heightened maneuverability of welding equipment, and also in portable installations
Welding manipulators: with hollow body for automatic welding of type MAS-2 (construction TsNIITMASh); for automatic welding of type T-25 (construction IES); for hand and semiautomatic welding of type SM-1000 and SM-5000 and for hand, semiautomatic and automatic welding of type USM-1200 and USM-5000 (construction VPTI TYaZhMASh)	For slope and rotation of articles during hand and automated welding in unit and serial production

Universality and convenience of use of welding tractors has lead to creation of various constructions of this equipment. GOST 8231-56 anticipates three types of constructions: monoelectrode automatic tractor machines – on 500, 1000 and 2000 a.


.Fig. 18. Constructive diagram of installation for automatic welding under flux; 1 – roller-support; 2 – welding head; 3 – bunker for flux; 4 – coil for wire; 5 – cart with turning table; 6 – lifting platform; 7 – control panel; 8 – fluxing pad; 9 – bicycle cart; 10 – point of power supply.

For hard-facing operation there are produced special machines of construction IES. In a number of cases it is possible to attach for this purpose existing metal-working equipment.

Autowelding equipment is equipped, as a rule, with auxiliary devices (bunkers for flux, flux suctions, coils for electrode wire, copy rollers, light indicators etc.). For automation of direction of electrode with respect to welded edges a follow-up system is developed. For instance, a welding head of type L for a pipe-welding machine built at TsNIITMASh is equipped with a follow-up system with a photocopy device FKU-30 of construction TsKB "Electric drive." Recently a follow-up system for direction of electrode has also been developed at IES, VNIITMASh, NITI and other organizations.

Significant propagation has been enjoyed by hose semiautomatic machines and automatic machines, used for welding with an electrode wire in diameter 1.6-2 mm on constant or alternating current of 200-500 a. At IES has been developed a hose semiautomatic machine of type PSh-5 with hose 3.5 m in length equipped with special holders with a flux bunker for different operations, and modernized

semiautomatic machines of type PSh-54. The factory "Electrician" has built hose automatic machines of type ADSh-500 and semiautomatic machines of type PDSh-500, replaced later respectively with an ADShM-500 and PDShM-500. Hose automatic machines differ from semi-automatic machines by the presence of a small-size carriage with electric drive. In hose semiautomatic machines of the factory "Electrician" (as distinguished from semiautomatic machines IES) is foreseen a pneumatic supply of flux. Hose semiautomatic machines also can be adjusted for welding by open arc with magnetizing fluxes on a current near 300 a and for welding in carbon dioxide in steam.

Electroslag Welding

Fusing of electrode and basic metal during electroslag welding occurs thanks to liberation of heat during passage of current through a slag bath limited from the sides by two flat faces of welded sheets and two copper forming sliders, cooled water. The diagram of the process of electroslag welding is shown in Fig. 19. The seam usually is welded in a vertical position after one passage (immediately for all thickness of welded parts) in the direction from bottom to top. Besides welding, the electro-slag process is applied also for hard-facing, repair of parts, melting of ingots (for high-alloy steels) and certain other cases. In a number of cases (for instance, for a large volume of welding operation) electroslag welding of metal is expedient starting from a thickness of 25-30 mm; the upper limit practically is not limited (cases are known of electrodes of parts in thickness up to 2 m for

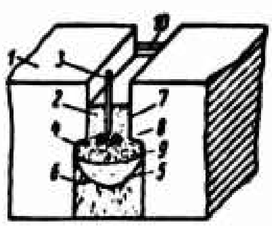


Fig. 19. The schematic diagram of the process for electroslag welding: 1 — welded part; 2 — slag bath; 3 — electrode; 4 — melted basic metal; 5 — metallic bath; 6 — welded seam; 7 — edges of welded part; 8 — drops of electrode metal; 9 — hot-test zone of welding bath; 10 — copper slider.

a length of seam 3 m). Thanks to great productivity, comparatively small expenditure of flux and electric power, high mechanical properties, absence of division of edges, insignificant deformation and the advantages the electroslag process has been the basic method of welding of thick-walled constructions from rolling, casting and forgings in heavy machine building (drums of boilers, stands, architraves, cylinders and other parts of presses, stand and frame of rolling mills, shafts, wheels and other parts of hydroturbines, thick-walled vessels etc.).

Methods of welding and forms of joints. Different methods of electroslag welding are shown in Fig. 20, and forms of welded joints — in Fig. 21. For welding of shaped sections of an article butt-to-butt usually a right-angle form is given. Most convenient for welding are rectilinear and annular seams. Welding of seams on cylindrical and spherical surfaces of a motionless article of large radius (3-6 m and above) is possible, if deflection of the tangent to the seam from the vertical does not exceed 10-30°.

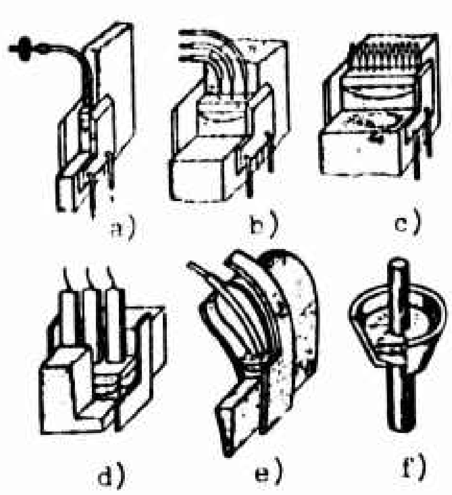


Fig. 20. Basic methods of electroslag welding: a) without reciprocating motion of electrode wire; b) with reciprocating motion of electrode wire; c) multielectrode; d) laminar electrodes; e) consumable neck; f) contact-slag.

Materials. During selection of materials for electroslag welding it is necessary to consider that the content of electrode metal in the seam is 50-75%. Therefore its property during electroslag welding to a larger degree than during arc under flux, depends on the composition of the electrode material.

Electrodes during electroslag welding are used in the form of wires (usually

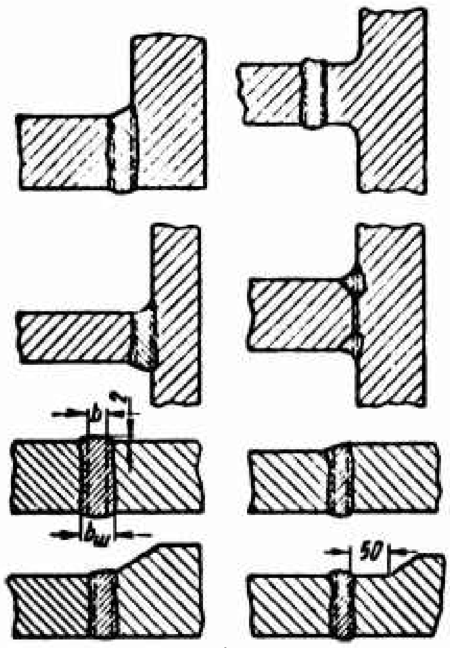


Fig. 21. Forms of joints during electroslag welding.

1-3 pieces rarely 4-20 pieces in diameter 2.5 and 3 mm by GOST 2246-60 and ChMTU), plates (1-3 piece and larger, thickness 8-12 mm, width 80-150 mm) and their combinations (consumable neck). Thanks to good mixing in the melting pool simultaneous use of electrodes of different chemical composition is possible. This allows obtaining of various compositions of electrode metal. Regulating still the depth of melting of the basic metal, it is possible at the expense of its mixing with the electrode metal to obtain also a welded seam of given chemical composition.

During welding of steels of brands 15, 15L, St. 2 equidurable joints can be obtained, using wire of Sv-08 or Sv-08A. During welding of boiling low-carbon steels for suppression of reaction of formation of SO (causing pores in the seam) wire Sv-08GS or Sv-12GS is used (in the latter case desirably in combination with Sv-08A). For welding of carbon steels with a content of carbon to 0.25-0.30% (for instance, steel 22K), and also certain low-alloy steels (for instance, steel 09G2DT) separate or joint application of wires of Sv-10G2 and Sv-08G2S is recommended. With an increase in the content of alloy elements in welded parts, it is expedient to increase the durability of the seam by means of its additional alloying at the expense of large melting of basic metal.

For welding of alloy steels where in addition to ensuring mechanical properties the welded seam must frequently satisfy special

requirements (thermal stability, resistance to corrosion, etc.) it is most expedient to use an electrode metal close in chemical composition to the basic one. In this case frequently plates and consumable necks are used of identical composition with the basic metal. Adjustment of composition of the seam during welding by a consumable neck (for instance, lowering of content of carbon) is attained by selection of the appropriate wire.

Electroslag welding of titanium and cast iron also is produced by plates of analogous compositions in combination with fluxes (respectively) AN-T2 and ES-5.

For electroslag hard-facing of wear-resisting steel powder wires are the most convenient. In particular, steels type Kh12 are fused by powder wires of brands PP-Kh12VF/ESh, PP-Kh12N4F/ESh and others in combination with flux AN-22; high-speed cutting steels type R-18 also are fused by corresponding powder wires with flux AN-22 and rods R-18 with a fluoride flux; for hard-facing steel 3Kh2V8 rods are used of analogous composition in combination with fluoride flux. For welding of carbon and low-alloy steel fluxes are recommended AN-8, AN-8M, FTs-7, AN-22. It is also possible to use fluxes OSTs-45 and AN-348A. For high-alloy steels "oxygen-free" fluxes are used (on the basis of technically fluoride calcium) brands ANF-1 (not less than 92%, CaF_2), ANF-7 (20% CaO), ANF-6 (35% Al_2O_3), 48-OF-6 and others. For excitation of the electroslag process with electrodes of heavy-gage flux AN-25 (30-40% TiO_2) is used which is electroconductive in the solid state.

Mechanical properties of welded joints. Natural heating edges above a slag bath (autoheating), slow heating and cooling of the weld-objected zone lowers the danger of appearance of cracks during welding. The great volume of melting pool above the crystallized metal promotes

Fig. 22. Macrograph of seam on metal of thickness 250 mm, carried out by electroslag welding.

its degassing and surfacing of nonmetallic particles, and also to a significant degree prevents appearance of shrinkage cavities and cracks in the seam. At the same time, large width of the weld-affected zone (16-18 mm) and duration of its stay at high temperature, and also special conditions of crystallization of seam lead to formation in the welded joint of separate zones with macrocrystalline structure (Fig. 22). Therefore, for crushing of structure and obtaining of stable values of shock viscosity of the welded joints, the responsible structures usually are subject to normalization with subsequent tempering (for removal of residual stresses).

Mechanical properties of welded seams on certain steels are given in Table 17. Durability of welded joints (with assumed strengthening) of steel type 22K during cyclical load (investigated in TsNIITMASh on large samples in section up to 40,000 mm^2) is close to the durability of the basic metal, but during surface riveting of welded joint, it exceeds the latter.

<u>Conditions</u>. Voltage and current are the basic power parameters of the conditions. Besides them, on the process of welding and the welded joint, the rate of supply $v_э$, section $F_э$, quantity n and "dry" departure $l_э$ of the electrodes, speed of oscillation $v_к$ (reciprocating shift) and time t of stops for sliders, gap between edges b, depth of slag bath $h_ш$ and certain other factors also render an influence.

Table 17. Mechanical Properties (Average) of Seams Made by Electroslag Welding

Brand of welded steels	Thickness of metal in mm	Brand of wire	Brand of flux	Yield point in kg/mm^2	Temporary resistance in kg/mm^2	Elongation per unit length in %	Relative narrowing in %	Shock viscosity in $kg \cdot m/cm^2$
22K	450	Sv-10G2	FTs-7	28	46	28	70	13
25L	450	Sv-08GA	AN-8	29	48	28	59	12
35L	280	Sv-08GA	AN-8	30	51	30	66	11
20GS	230	Sv-10G2	AN-8	32	50	31	65	14
16GNM	135	EI569	FTs-7	33	51	28	67	15
15KhMA	40	Sv-12KhM	FTs-7	31	47	33	66	14
30KhGSA	30	Sv-18KhMA	AN-22	102	114	13	37	4
25Kh2MF	100	EI913	48-OF-6	73	63	20	75	15
30Kh2N2M	100	Sv-10G2	AN-8	65	79	22	65	15
25Kh3NM	100	EI616	AN-8	60	74	24	68	15
25Kh3NM	100	Sv-10G2	AN-8	42	59	29	72	18
35KhN3M	100	Sv-10G2	AN-8	62	75	18	66	10
35KhN3M	100	EI681	AN-8	49	80	18	46	12

Note: Heat treatment for steels of first 6 brands — normalization and tempering, for others — hardening and tempering.

Table 18. Influence of Conditions of Electroslag Welding on Form and Composition of Seam

Parameters of condition of welding	Change of characteristics of seam with increase of parameters of conditions of welding			
	Width ($b_{ш} = 30-60$ мм)***	Depth of metallic bath ($h_{ш} = 10-15$ мм)***	Form factor of metallic bath $\left(K_{ф} = \frac{b_{ш}}{h_{ш}} = 2-4\right)$	Share of basic metal of seam $\left(\gamma = \frac{b_{ш} - b}{b_{ш}} 100 = 25-60\%\right)$
Speed of supply of electrode and current ($v_{э}$ = 150 to 250 m/hr; I = 400 to 500 a)* To 200 m/hr, to 400 a	Increased	Increased	Insignificant decreases	Insignificantly is increased
Above 200 m/hr; above 400 a	Decreases	The same	Decreases	Decreases
Thickness of metal on electrode** ($\delta_{п}$ = 75 to 125 mm)	Insignificant decreases	Decreases	Increased	Insignificant decreases
Voltage of welding (U = 42 to 48 v)	Increased	Insignificantly is increased	The same	Increased
Speed of transverse shift of electrode ($v_{пп}$ = 30 to 35 m/hr)	Decreases	Is not changed	Decreases	Decreases
Depth of slag bath ($h_{ш}$ = 40 to 50 mm)	The same	Insignificant decreases	The same	The same
Magnitude of dry departure of electrode (l_{c} = 60 to 70 mm)	Is not changed	Decreases	Insignificantly is increased	Is not changed
Magnitude of gap (b = 25 to 30 mm)	Increased	Is not changed	Increased	Increased

*On electrode wire of diameter 3 mm.

**With a motionless electrode wire δ/n < 60 mm.

***In parentheses are shown mean values of characteristics of seam and parameters of conditions of welding for carbon and low-alloy steel.

Table 19. Certain Characteristics of Basic Apparatuses for Electroslag Welding

Type of apparatus and its assignment	Biggest thickness of welded metal in mm	Movement of apparatus along seam	Type of electrode	Quantity of electrodes	Kind of welding
A-501-M for welding of corner and butt joints	90	Directly by article	Wire $\phi 2.5$ mm	1-2	Constant
A-612 for welding of longitudinal seams of butt joints	100	The same	Wire $\phi 3$ mm	1	Variable
A-350 for the same	180	The same	The same	1-3	The same
A-433-M* for the same	60	By column	The same	1	Constant
A-372-R for welding of longidudinal and annular seams of butt and corner joints	350 wires 600 plates	The same	Wire $\phi 3$ mm and plates	1-3	Variable
A-535 for the same	500 wires 800 plates	The same	The same	1-3	The same
A-550 for welding of short seams ..	250	The same	Plates	1-3	The same
A-578 for butt hard-facing	—	By column	Rod $\phi 14$-20 mm	1	Variable

*Apparatus A-433-M is used also for vertical electric arc welding under flux of metal of thickness 15-20 mm.

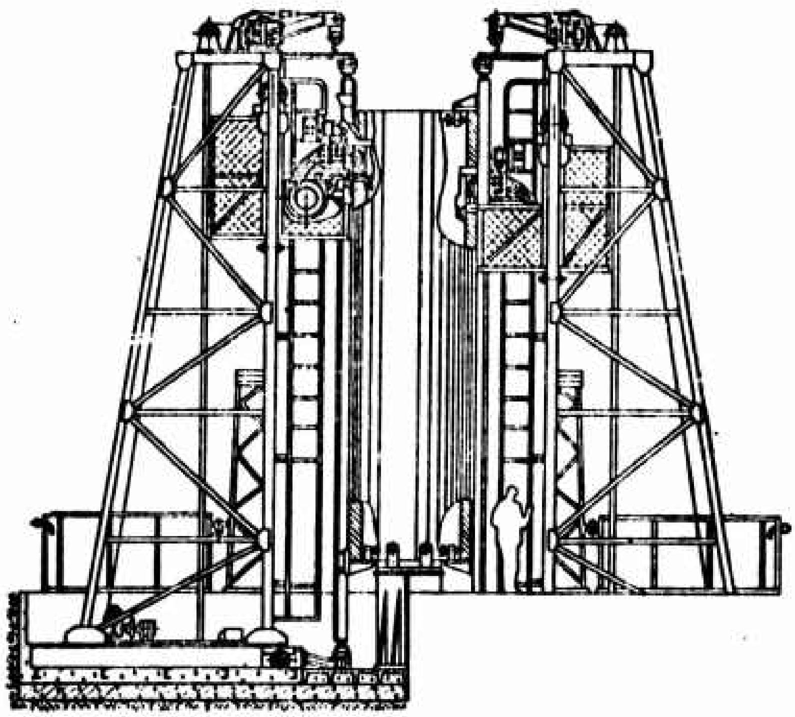


Fig. 23. Constructive diagram of installation for electroslag welding of longitudinal seams.

In view of the large number of parameters, establishment of optimum conditions of electroslag welding presents known difficulties. Preliminary calculation of the basic parameter — voltage in the melting pool depending on the given depth of penetration of edges — may be done, proceeding from the equation of heat balance of the slag bath by the method, presented in the literature [3]. For preliminary selection of conditions in Table 18, the dependences of form of seam on certain parameters of condition and their average values for welding of carbon and low-alloy steel are given.

Apparatus and equipment. Basic samples are developed by IES. All of them act on the principle of self-regulation of fusing of wire, which moves with independent (of voltage on melting pool) speed. Speed of vertical shift of apparatuses depending upon location of level of melting pool can be automatically regulated with the help of appropriate devices. In Table 19 are given basic characteristics of certain apparatuses for electroslag welding. Sources of supply (see Table 3) are recommended with rigid characteristics.

Inasmuch as time for installation of apparatuses for welding of different articles is very great, in VPTI TYaZhMASh are developed

mechanized devices, allowing significant acceleration of fulfillment of auxiliary operations by installation of electroslag apparatuses for welding in the article. In a number of factories there exist different mechanized installations for electroslag welding. In Fig. 23 is shown an installation for electroslag welding of longitudinal seams. Installations for electroslag welding of longitudinal seams. Installations for electroslag welding of annular seams in structural diagram are similar to corresponding installations for automatic welding under flux of heavy cylindrical articles.

Automated Welding in Carbon Dioxide

Welding of steel in carbon dioxide as compared to manual welding of thick-covered electrodes differs by higher productivity (by 1.5-2.5 times) economy and best conditions of work (less specific separation of dust and gases). Thanks to this, and also high maneuverability, possibility of welding in all space positions, good mechanical properties of seam and other positive qualities, welding in carbon dioxide, in spite of the comparative novelty of the method* it has won acknowledgement as a universal means of wide mechanization and automation of welding production.

Materials. Carbon dioxide protects the melting pool from air. However as a result of the oxidizing action of the gas medium in the zone of the arc during welding in carbon dioxide the electrode wire (Table 20) for carbon and low-alloy steel should have in its composition elements of a deoxidizing agent (usually silicon and manganese).

*Welding in carbon dioxide with a molten electrode was developed at the TsNIITMASh by K. V. Lynbavskiy and N. M. Novozhilov (patent No. 104283, February 2, 1952).

Table 20. Electrode Wire of Certain Brands (By GOST 2246-60) for Welding in Carbon Dioxide

Brand of wire	Basic assignment
Sv-08GS	Responsible constructions from low-carbon and low-alloy steel
Sv-08G2S	Responsible construction from low-carbon and construction alloy steel by GOST 5058-57
Sv-10KhG2S	Thick-walled constructions of steel 20GS, 20GSL and analogous ones
Sv-18KhGSA	Construction from average alloy steels 20KhGS, 30KhGS and others
Sv-18KhMA Sv-10GSMT	Thin sheet constructions from alloy steel with heightened content of silicon and manganese
Sv-08KhG2SM	For welding of heat-resisting steel 15KhMA, 20KhM, 20KhMA
Sv-08KhGSMF	For welding of heat-resisting steel 20KhMFL and analogous
Sv-08Kh3G2SM	Heat-resisting steel with heightened content of chromium
Sv-08Kh14GT	Chromous steel type 1Kh13 and 2Kh13
Sv-06Kh14	The same, with thickness to 4 mm
Sv-10Kh17T	Chromous steel type Kh17 and Kh17T
Sv-06Kh19N9T	Single pass seams on steel type 1Kh18N9T
Sv-08Kh20N9G7T	Austenitic-ferrite steel 1Kh20N3G3D2L with steel 20GSL

Most widely used for welding still is foodstuff carbon dioxide by GOST 8050-56 (carbon dioxide liquified) in bottles, containing not less than 98.5% CO_2 and not more than 0.1% water (in free form in bottles with liquid carbon dioxide). In dried foodstuff carbon dioxide (produced by certain factories under special technical conditions) water in free form is absent, and the content of dissolved water does

not exceed 0.4%. Inasmuch as impurity in carbon dioxide negatively affects the process of welding and lowers the quality of seams, in TsNIITMASh are developed special technical conditions, by which welding carbon dioxide should contain CO_2 not less than 99.5%, and content of water is established the same, as in dried.

Storage and transportation of bottles have to be done in strict conformity with corresponding "Rules," affirmed by the Ministry of Electric Power Stations. On every lot of bottles with carbon dioxide should be issued a document with indicators of the quality of production.

Most prospective in a number of cases is the use of dry ice for welding in carbon dioxide. For a large volume of welding in a factory it is expedient to transport liquid carbon dioxide in special vessels of large volume and organize a central point, from which carbon dioxide via pipelines will proceed to the operational location.

Properties of seams. In carbon dioxide it is possible to weld many steels, for which manual arc welding is used and automated welding under flux and in argon. The metal of the seam welded in carbon dioxide, differs by minimum content of nitrogen and hydrogen, slag inclusions, and also sulfur and phosphorus. Inasmuch as during welding in carbon dioxide, melting is somewhat deeper than during welding under flux the property of single pass seams depends somewhat more on the composition of the basic metal. During welding of multilayer seams the chemical composition and mechanical properties of the first layers and subsequent layers in a number of cases do not coincide.

In Table 21 are given data, indicating high mechanical properties of seams, welded in carbon dioxide on a number of construction steels.

Table 21. Mechanical Properties (Average) Seams, Welded in Carbon Dioxide on Certain Construction Steels

Brand of welded steels	Temporary resistance to break in kg/cm^2	Yield point in kg/cm^2	Elongation per unit length in %	Relative narrowing in %	Shock viscosity in $kg \cdot m/cm^2$
M18	56; 51	35; 31	25; 27	57; 63	11; 12
M26	64; 57	52; 43	18; 23	61; 45	9; 13
22K	53; 48	42; 34	27; 32	70; 72	19; 21
20GSL	61; 49	48; 35	21; 30	61; 68	9; 19
14G2	61	43	24	58	11
14KhGS	67	46	18	39	8
15KhSND	65	46	22	55	10
10KhGSND	64	50	18	51	9
09G2	59	44	25	61	19
30KhGSA	84	62	14	47	8
30KhGSA	125	—	—	—	7

Note: Figures in the left column of every column pertain to single pass seams or the first layer of a multilayer, in the right, to middle and upper layers. Thickness of steel M26 — 50 mm, 22K and 20GSL — 90 mm, 30KhGSA (last line) is 3 mm, others 12-16 mm. Welding current and heat treatment: 22K — 300 a, tempering 670° (3.5 hr); 30KhGSA — 250 a, tempering 520° (penultimate line) and 150 a, hardening 890° (last line); other steels — 300-400 a, without heat treatment. Welding wire: M18, M26 — Sv-08GS; 30KhGSA — Sv-18KhMA; other steels — Sv-08G2S.

Welded seams on heat-resisting steels of perlitic class 15KhMA, 20KhM, 20KhMA, 20KhMFL, 15Kh1M1F by stability of composition after aging, brief mechanical properties during normal and operating temperatures, and also by prolonged durability and creep during operating temperatures correspond respectively to the indices of the basic metal (for condition of selection of optimum composition of electrode wires, conditions of welding and heat treatment). During observance of this condition seams on chromous steels 1Kh13, 2Kh13, Kh17T, Kh172N and single-pass seams on chrome-nickel type 1Kh18N9T

also correspond to requirements presented to basic metal. For guarantee of corresponding properties in a number of cases it is necessary to apply powder wire. In particular, IES recommends for spread Kh172N powder wire of composition 1Kh18N2GTA and for austenitic-ferrite steels 1Kh20N3G3D2 – 1Kh20N5G3D2 (with addition to 0.5% Na_2SiF_4 for preventing of pores).

Conditions. Basic parameters of conditions of welding are: welding current, diameter of electrode wire, voltage at the arc, speed of welding, expenditure of carbon dioxide, boom and slope of electrode. Influence of parameters of conditions of welding in carbon dioxide on form of seam is approximately the same, as during welding under flux (see Table 8).

Welding in carbon dioxide is done on direct current, where as a rule, the positive pole of the source of feeding is connected to the electrode.

The recommended limits of welding current depending upon diameter of the electrode wire are the following:

Diameter of wire in mm	0.5	0.8	1.0	1.2
Welding current in a	30-60	50-100	70-150	100-200
Diameter of wire in mm	1.6	2.0	2.5	3.0
Welding current in a	150-350	200-500	300-700	450-800

Arc voltage U_∂ depending upon welding current I may be (in first approximation) expressed by the following formula:

$$U_\partial = 16 + 0{,}035\, I.$$

Fig. 24. Macrograph of horizontal multi-passage seam on vertical sheets (thickness 100 mm with K-shaped division), welded in carbon dioxide.

By welding in carbon dioxide it is possible to execute the same joining, as under flux; form of preparation of edges may be taken by GOST 8713-58. As an example in Fig. 24 is shown a welded joint, carried out in carbon dioxide.

Tentative conditions of welding of butt joints are given in Table 22, of corner joints, in Table 23.

The number of layers of a seam depending on the roll of the corner seam is the following:

Roll of seam in mm	6-8	9-12	13-14	15-16	17-18
Number of layers	1-2	2-3	4	5	6

Roll of seam in mm	19-20	21-24	25-26	27-30
Number of layers	7-8	9	10	12

Conditions of welding by electrorivets and depth of meltings are given in Table 24.

Conditions of welding of steel with heightened content of carbon and alloy steel are close to those given in Table 22 and 23. However during their welding one should consider certain additional conditions. Thus, for instance, for welding steel type 30KhGS, perlitic heat-resisting steel and chromous steel of more than 8-10 mm preliminary heating to 250-300° is needed. Welding of austenitic steel is recommended to be done at a somewhat lowered current and higher speed.

Table 22. Tentative Conditions of Welding in Carbon Dioxide of Butt Joints

Thickness of metal in mm	Total number of layers of seam	Diameter of electrode in mm	Current in a	Voltage on arc in volts
0.6-1.0	1	0.5-0.8	50-60	18
1.2-2.0	1-2	0.8-1.0	70-110	18-20
3-5	1-2	1.6-2.0	160-200	22-24
6-8	2	2	280-300	28-30
8-12	2-3	2	280-300	28-30
12-18	2	2	380-400	30-32
20	2	2.0-2.5	440-460	30-32
25	4	2.0-2.5	420-440	30-32
40 and greater	10 and greater	2.0-2.5	440-500	30-32

Note: Speed of welding 16-25 m/hr, metal in thickness to 8 mm welded without cutting of edges.

Table 23. Approximate Condition of Welding of Corner Joints in CO_2 Gas

Roll of seam in mm	Diameter of electrode in mm	Welding current in a	Voltage of arc in volts	Consumption electrode in mm
2.5-3.0	1.0	75-120	18-19	8-10
3.0-4.0	1.2	120-150	20-22	12-14
5.0-6.0	1.6	260-280	27-29	18-20
7.0-9.0	2.0	300-350	30-32	20-24

Note: Speed of welding 20-30 m/hr.

Table 24. Tentative Conditions of Welding by Electrorivets in Carbon Dioxide

Diameter of electrode in mm	Welding current in a	Voltage in volts	Time of welding in sec	Depth of melting in mm
1.6	220	27-30	0.5	2.5
1.6	260	30-32	0.5	4.0
2.0	300	32-34	1.5	2.3
2.0	350	32-34	1.5	3.5
2.0	450	35-37	1.5	6.0

During welding of the indicated steel it is required to execute seams without notches accurately, to fill craters and to observe other conditions, lowering the probability of appearance of cracks.

Welding of edges of thin-sheet steels can be done by a coal electrode in diameter 2-6 mm at a current up to 150 a (direct polarity) in any space position. Expenditure of carbon dioxide is 600 liter/hr. For butt joints of small thickness welding with a tungsten electrode additionally protected by argon from oxidation by carbon dioxide may be used with supply of an additional wire.

Apparatus and equipment. Installation for semiautomatic and automatic welding in carbon dioxide by principle of action is similar to corresponding installations for welding under flux. The distinction between them consists mainly in the system of supply of protective medium (gas or flux). Therefore at the first stage of introduction of welding in carbon dioxide into the production, many plants reequip reserve semiautomatic machines PSh-5, PSh-54, PDSh-500 and PDShM-500 and automatic machines of ADS-1000, UT-1500, TS-17 and others for welding in carbon dioxide. In 1958-1960 already began centralized production of apparatus and equipment for this purpose.

Table 25. Apparatus and Equipment for Welding in Carbon Dioxide

Forms of apparatus and equipment	Types of construction and assignment				
Semiautomatic machines	A-547 and A-607 (IES) P-130 (UkrdortransNII). For welding of metal of small thickness at a current of 30-200 a with a wire ϕ 0.5-1.2 mm	A-537 (IES). For welding of metal of average and large thickness at a current of 200-500 a with a wire ϕ 1.6-2 mm	PDPG-500 (VNIIESO). For welding of metal of small, average and large thickness with a current of 60-500 a by a wire ϕ 0.8-2.0 mm	PGSh-4 (TsNIITMASh). For welding of metal of average and large thickness with a current of 200-500 a by a wire ϕ 1.2-2 mm	USA-2 (NII Traktorosel'khozmash). Universal apparatus for semiautomatic, automatic and electrorivet welding at a current of 100-600 a with a wire ϕ 0.8-3 mm
Automatic machines of general assignment	ADPG-500 (VNIIESO). Tractor for welding of metal of small, average thickness at a current of 60-500 a by a wire ϕ 0.8-2.5 mm	ADS-1000 ("Elektrik"). Tractor, adjusted for welding in carbon dioxide of metal of average and large thickness by a current of 200-700 a with a wire ϕ 1.6-3 mm	UT-1250-3 (TsNIITMASh)	TS-17M (IES) (see text to ADS-1000)	ABS (IES) Universal apparatus
Automatic machines for welding of annular seams	R-922 (IES). Machine for hardfacing of internal surfaces of cylindrical and conical matrices in external diameter 150 mm, length to 1100 mm, weight to 1800 kg at a current of 120-480 a with a wire ϕ 2-3 mm	R-964 (IES) Machine for welding of 1 or 2 seams of parts in diameter to 300 mm with a horizontal axis of rotation at a current of 40-200 a with a wire ϕ 0.5-1.2mm	S-55 (TsNIITMASh). Universal installation for welding of pipes ϕ 20-100 mm, length 200-3000 mm and diameter to 300 mm with vertical axis at a current of 60-200 a by a wire ϕ 0.8-1.2 mm	P-912 (IES) Three-position machine for welding of articles in diameter to 200 mm with vertical axis of rotation at a current of 40-200 a with a wire ϕ 0.5-12 mm	ADK-500-3 (VNIIESO). Automatic machine for welding of annular seams ϕ 75-300 mm, at horizontal and slanted positions of table at a current of 200 to 500 a by a wire ϕ 1.6-2.5 mm
Specialized automatic machines	A-451 (IES) Machine for welding by a corner electrode ϕ 2-4 mm at a current to 60 a with edges of round thin-walled capacitors. Productivity 400 pieces per hour	A-595 (IES) Machine for welding of canisters by a carbon electrode ϕ 6 mm at a current up to 200 a	R-899 (IES). Automatic machine for assembly and welding of spheres ϕ 200 mm by a wire ϕ 1 mm on a current up to 200 a. Productivity up to 60 pieces/hr	A-489 (IES) Machine for welding of diaphragms of steam turbines on a current of 300-340 a with a speed of 18 m/hr	(VNIIST). Installation for welding of nonrotating joints of pipelines

Note: In those cases where the material of the electrode is not shown, welding is executed by a steel wire.

In Table 25 are given brief characteristics of basic forms of apparatus and equipment for welding in carbon dioxide, completed by corresponding sources of supply in Table 3. For welding at a current less than 250-275 a sources of supply are needed with rigid characteristic; for large current it is possible to use also generators of type PS-500.

Argon Arc Welding

Essence of process. During argon arc welding protection of the molten metal from the influence of air is carried out by supply of a neutral gas – argon – in the zone of arc (Fig. 25). For welding it is recommended to use well deoxidized metals or alloys.

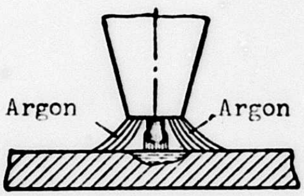


Fig. 25. Diagram of protection of arc and melted bath by argon.

Argon arc welding may be done by a nonconsumable (tungsten rod) and a consumable electrode (wires, close in chemical composition to the basic metal).

During welding with a nonconsumable electrode four methods are used:

manual – small parts or parts having complicated configuration are welded;

mechanized – used, when additional wire is not required; exact assembly of welded parts is necessary; burner shifts along welded edges by a mechanism; during welding of annular seams, conversely, burner stands in place, but piece shifts;

automatic – motion of burner and supply of addition wire are produced automatically; applied, if it is necessary to have reinforcement of the seam or it is impossible to ensure required accuracy of assembly during welding without addition.

Mechanized and automatic welding are carried out on special automatic machines;

hose semiautomatic — welding is executed with help of a special holder. Welder manually moves holder along welded part, maintaining constancy of length of arc, addition wire through flexible hose automatically moves by a special mechanism, fixed at a certain distance from the welder.

Welding by a consumable electrode can be carried out by two methods:

hose semiautomatic — with the help of a special holder, produced in the form of a pistol. Wire moves automatically through flexible hose;

automatic — special automatic machines.

During automatic welding of longitudinal seams of great length in spite of the presence of directrices, it is necessary to correct the motion of the arc manually. In automatic machines for argon arc welding by the nonconsumable electrode also constancy of length of arc is maintained manually. Recently heads with a follow-up system have been built ensuring conducting of electrode along the line of the joint. Also a head, automatically supporting the length of arc on automatic machines for argon arc welding by a tungsten electrode has been developed.

Sources of supply. Argon arc welding by a consumable electrode is done with direct current of reverse polarity; sources of supply are recommended with rigid or increasing (in working part) external characteristics.

Welding with a nonconsumable tungsten electrode of steel titanium and copper alloys is done on direct current of direct polarity. As

sources of supply are used standard welding generators with steeply dipping external characteristics or welding rectifiers of type VSS-120-3 and VSS-300-3.

During argon arc welding by a tungsten electrode of light alloys (aluminum and magnesium) the sources of supply must meet special requirements [26], which are conditions, first, by the presence of electrodes with warm-physical properties (tungsten and aluminum) sharply differing from each other and, secondly, necessity of removal of oxidized film from the surface of the melted bath.

At present industry releases three types of sources of supply for argon arc welding of light alloys by a tungsten electrode — UDAR-300 and UDAR-500 (factory "Electrician," Leningrad) and IPK-350 (Rzhev).

<u>Welding of aluminum and magnesium alloys.</u> During manufacture of welded constructions from aluminum and magnesium alloys, argon arc welding by comparison with other methods of welding by fusing has an essential advantage. With this method flux is not used and almost no overheating of metal occurs. Structure of fused metal and transition zone is obtained fine-grained.

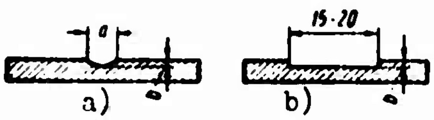
<u>Welding by a tungsten electrode</u> is used mainly for thin (to 4 mm) material, and also for short seams and seams of complicated configuration.

Oxidized film from the surface of bath is dusted by ion bombardment of argon. It does not reform, since the arc burns in an atmosphere of inert gas. The oxidized film from the seam departs as a result of difference in specific gravity of aluminum (2.7 g/cm^3) and the oxidized film (3.85 g/cm^3). In order to assure departure of the film from the seam welding of butt joints is done on a lining with a groove. During manual welding, a lining is not required, since the film is lost in fusion.

During mechanized and automatic welding of butt joints, if it is necessary to obtain seams with full melting during welding on one side, a lining from the reverse side of the seam is obligatory, otherwise burns are formed. In the lining under the joint a groove is made on the bottom of which in the process of welding an oxidized film forms.

Limit of strength of welded joint for alloy AMg6, carried out on a lining without groove, is equal to 22.1 kg/mm^2, with groove 31.7 kg/mm^2.

Linings (Fig. 26) are made from copper or from stainless steel. Deep grooves lead to overheating of metal of seam and formation of sharp transitions from fused metal to basic that may cause lowering of durability of the welded joint.



Thickness of material in mm.	a	b
< 2	5	0,8±.1
2.4	6	1,2±0,1

.Fig. 26. Form and dimension of grooves for welding of aluminum alloys: a) spherical; b) right-angle.

Remaining linings (Fig. 27) are made from material, close in chemical composition to the basic, and preliminarily welded to the parts by spot or manual argon arc tack welding.

Welding of butt joints should be done in special clamp attachments (Fig. 28), ensuring tight pressing of welded edges to the lining. During welding of annular seams of a shell they are collected and unclasped with the help of special unclasping rings.

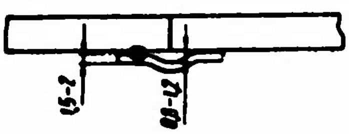


Fig. 27. Residual lining, applied during welding of locking seams.

Types of welded joints for argon arc welding with a tungsten electrode are shown in Table [illegible]. Welded edges or the entire part before welding

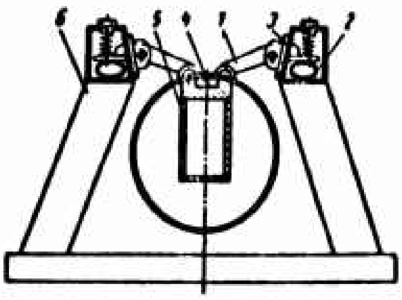


Fig. 28. Diagram of clamp attachment for welding of longitudinal seams: 1 — clamp lug; 2 — rubberized hose; 3 — upper support beam; 4 — lining; 5 — lower support beam; 6 — dock.

is subjected to etching.

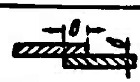
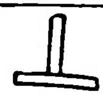
If parts after etching for 8-10 hours or more are not welded, the welded edges are subjected to stripping by metallic, defatted brushes. In the process of transportation and assembly of etched parts welded edges do not have to be soiled. These operations are recommended to be done in clean white gloves.

For welding of aluminum and magnesium alloys pure argon is recommended, first composition, with content of nitrogen not more than 0.04% and oxygen not more than 0.005%; humidity of it does not have to exceed the value corresponding to the point of dew minus 40°C. As electrodes one should use pure tungsten.

During manufacture of welded constructions aluminum-magnesium unsubstantiated by heat treatment alloys find wide application (Table 27).

Work hardened alloys have high strength before welding. If after welding of the part or unit it is possible to subject it to work-hardening heat treatment, then the durability of the welded joint is increased (Table 28). However full heat treatment after welding can be used for small parts. More acceptable for production by variant would be full heat treatment before welding and aging after welding, but in this case durability of the welded joint almost is not increased. In thermoprocessed alloys the angle of bend of the welded joint, characterizing to a certain degree its plasticity, is found to be lower than for thermounprocessed, which can lead to lowering of constructive durability. Constructive durability of

Table 26. Types of Joinings During Welding by a Tungsten Electrode of Aluminum Alloys

Welding	Thickness of welded material δ in mm	Form of preparation of edges	Dimensions in mm					
			a	b	c	h	r	$\alpha°$
Without addition	≤ 1.5		–	–	–	3.5	≤ 8	–
	> 1.5–3		–	–	–	4	≤ 8	–
	≤ 2		1.5	1.5	2	3.5	–	45
	> 2–3		2	2	2.5	4	–	45
With addition	1–5 *		≤ 0.5	–	–	–	–	–
	1–5 **		≤ 0.5	(4–6) δ	–	–	–	–
	4–8		≤ 0.7	1	–	–	–	70
	8–15		≤ 1	2	–	–	–	70
	≥ 1.5		–	10–15 ***	–	–	–	–
With addition	1.5–3		2–6	–	–	–	–	–
								
								

* Difference of thickness not more than 2 mm.
** Ratio of thicknesses not more than 1:2.
*** In necessity it is possible to designate from 5 mm (upper limit is not limited.)

Table 27. Mechanical Properties of Basic Metal and Welded Joints of the Most Widely Known Alloys on the Basis of Aluminum. Thickness of Material 2.5 mm

Brand of alloy	State of material to welding	Limit of strength of basic material in kg/mm²	Mean values of mechanical properties of welded joints			Coefficient of inclination to formation of cracks during welding* in %
			Limit of strength in kg/mm²		Angle of bend in degree	
			With strengthening	Without strengthening		
AMts	Annealed	11-13	Equi-durable to basic material	—	—	4.1
AMg	"	17-23	The same	—	—	21.9
AMg3	"	≥20	21.2	21.7	110	5.2
AMg5V	"	≥28	29.0	28.1	170	17.8
AMg6	"	≥32	35.6	34.1	105	5.8
D-16	Hardening and aging before welding. After welding aging	≥41	32.4	29.3	40	63
D-20	Hardening after aging	≥40	29.6	24.4	46.6	4

*Data are obtained during manual argon arc welding by a tungsten electrode on a cross-shaped sample.

Table 28. Mechanical Properties of Welded Joints from Alloys D16 and D20 in Thickness to 2 mm

Heat treatment	Limit of strength* in kg/mm² for alloy D-16	D-20
Annealing before welding and full heat treatment after welding	$\frac{40.7}{40.6}$	$\frac{41.1}{38.3}$
Full heat treatment before and after welding	$\frac{42.7}{40.4}$	—
Full heat treatment before welding and aging after welding	$\frac{32.4}{29.3}$	—

*In the numerator — during welding with strengthening, in the denominator — without strengthening.

welded joints from alloy D-16 and D-20 is significantly lower than from alloy AMg6. For cyclical loads, alloy AMg6 also showed good results with removed strengthening of the seam. Alloy AMg6 has good resistivity to repeated impact loads and possesses least inclination to formation of cracks [30].

Thus, for manufacture of welded structures by the method of fusing one should recommend alloys AMts, AMg3, AMg5V and AMg6. Of the magnesium alloys, alloy MA2-1 (Table 29) has the highest durability at the welded joint and the least inclination to formation of cracks during argon arc welding.

Table 29. Mechanical Properties of Welded Joints from Magnesium Alloys in Thickness 2.5 mm During Argon Arc Welding by a Tungsten Electrode

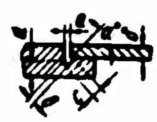
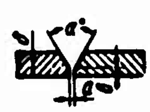
Brand of basic metal	Brand of addition wire	Ultimate strength of basic material in kg/mm^2	Mean values of mechanical properties of welded joints			Inclination to formation of cracks during welding in %
			Ultimate strength in kg/mm^2		Angle of bend in degree	
			With strengthening	Without strengthening		
MA8	MA-1	26	17	15	38	22
	MA5		18	22	78	26
	MA8		17	14	45	31
MA2-1	MA1	29	24	24	61	74
	MA2-1		24	26	68	36
	MA5		27	27	65	13
	MA8		24	23	67	—

On the basis of the data in Table 29 as addition material one should have recommended wire MA5, however there is information about lowering here the corrosion resistance of the fused metal. Therefore one should use wire, in chemical composition close to the basic metal.

Types of joints, recommended for welding of magnesium alloys, are given in Table 30, approximate conditions of butt joints from aluminum-magnesium alloys — in Table 31.

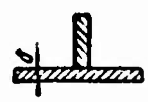
Welding by a consumable electrode is conducted at high densities of current that ensures large depth of penetration. This method is applied mainly during welding of thick material (5-6 mm and above). Essential deficiency of it is insufficient protection of molten metal

Table 30. Types of Joints During Welding of Magnesium Alloys

Thickness of material δ in mm	Form of preparation of edges	Dimensions in mm				
		a	b	c	d	$\alpha°$
1.5–5		$\leq$ 0,6	–	–	–	–
1.5–5		$\leq$ 0,6	2	2	$\geq$ 4	45
5–20		0,6–1,5	2–3	–	–	70–90
$\geq$ 20 (to 60)		0,6–1,5	2–3	–	–	70–90
$\geq$ 60*		1–2	2–3	–	–	70–90

*During welding of the first layers from the reverse side of the seam it is necessary to establish a lining by the shape of the division.

Table 30 (Continued)

Thickness of material δ in mm	Form of preparation of edges	Dimensions in mm				
		a	b	c	d	e'
≥ 5*		–	≤ 10	–	–	–
≥ 5*		–	–	–	–	–

*Overlap and T-shaped joints are better obtained during semiautomatic welding.

in the process of welding, as a result of which mechanical properties of the fused metal are lowered.

Thus, during welding of alloy AMg6 in thickness from 20-40 mm and above the limit of strength of the welded joint without strengthening with respect to durability of basic metal is:

during welding by a consumable electrode 0.7-0.8 σ_B and

during welding by a tungsten electrode 0.85-0.95 σ_B, where σ_B is the limit of strength of the basic material.

In order to improve protection of the arc, a burner with additional protection by argon is used, ultrasonic oscillations are introduced in the molten bath; the wire is subjected to electropolishing or vacuum heating.

Welding from one side of butt joints with full melting is done on detachable or residual linings.

During welding from two sides one should increase blunting of the edges, which have to tightly adjoin one another face to face. Welding is executed without full melting. After application of weld from one side, the part is rotated at 180°C. It is recommended to chisel

Table 31. Conditions of Welding of Butt Joints from Aluminum-Magnesium Alloys with Nonconsumable Electrodes

Welding	Thickness of material in mm	Number of passages	Diameter of electrode in mm	Current in a	Speed of welding in m/hr	Diameter of addition wire in mm	Speed of supply of wire in m/min	Expenditure of argon in liters/min
Mechanized without addition	1.2 2 2.5 3	1 1 1 1	3-4 4-5 4-5 4-5	130-150 220-240 230-250 260-280	36 36 30 30	– – – –	– – – –	8-10 10-12 10-12 10-12
Mechanized with addition	2 2.5 3 3.5	1 1 1 1	4-5 4-5 4-5 5-6	210-220 230-250 260-280 290-310	22 20 17 14	2 2 2 2	1.2-1.4 1.3-1.5 1.4-1.6 1.5-1.7	10-12 10-12 10-12 10-12
Manual	2 12	1 3-4	3-4 5-6	100-120 300-350	– –	– –	– –	10-12 12-15

the root of the first weld or select a special milling cutter and then do the welding.

During welding by a consumable electrode it is recommended to use a wire, close in chemical composition to the basic metal. The beginning and end of the seam one should conclude on technological plates or anticipate a somewhat large allowance.

Semiautomatic hose welding by a consumable electrode it is possible to execute in different space positions.

Tentative conditions of welding by a consumable electrode of aluminum alloys are given in Table 32.

Table 32. Conditions of Welding of Aluminum Alloys with a Consumable Electrode

Welding	Form of edges	Thickness of material in mm	Number of layers	Diameter of electrowire in mm	Current in a	Arc voltage in volts	Rate of supply of wire in m/min	Speed of welding in m/hr	Expenditure of argon in liter/min
Automatic		4	1	1.6	180–190	25–27	6–8	36	20–22
		4.5	1	1.6	180–190	25–27	6–8	33	20–22
		5	1	1.6	180–200	25–27	6–8	31	20–22
		6	1	1.6	180–200	25–27	6–8	26	20–22
		4	1	1.6	190–210	25–27	6–8	30	20–22
Semi-automatic		8	1	2	240–250	–	5–6	–	30–32
		12	2	2	260–290	–	5–6	–	30–32
		20	4–6	2	250–320	–	5–6	–	30–32
		60	12–14	2	230–350	–	5–6	–	30–32

Note: Large values of current during semiautomatic welding of joints with V-shape and X-shape division of edges correspond to welding of the root of the weld, but the smaller, to the external shafts of multi-layer joining.

<u>Welding of titanium and its alloys.</u> The basic problem during welding of titanium and its alloys is the creation of reliable protection of the melted bath from metal and zones, heated to high temperatures (greater than 700-800°C). Automatic and mechanized welding by tungsten electrode, ensuring good protection of the molten metal from contact with air, is used for titanium alloys in thickness ≤3 mm. For large thickness one should apply automatic welding under a layer of flux (brands ANT-1, ANT-3, ANT-5 and ANT-7).

For welding by a tungsten electrode for additional protection of the heated metal from the influence of air, to the burner is attached a shank (Fig. 29). During welding of annular seams in diameter less than 500 mm it should have a curvature, corresponding to the curvature of the article. After termination of welding one should continue the supply of argon as long as the surface of the seam and adjacent zones of heated up metal will not darken.

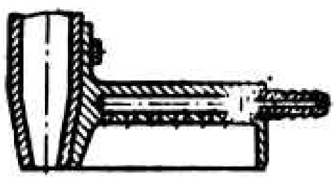


Fig. 29. Shank to burner for creation of additional protection of a seam from the influence of air during welding of titanium alloys.

At low rates (not exceeding 15 m/hr) welding may be done without a shank by burners with the usual nozzle with diameter of outlet 14-16 mm or one may use a nozzle of elongated form.

Argon for welding of titanium alloys should contain oxygen not more than 0.005% and nitrogen not more than 0.01%, dew point not above minus 40°C. As an electrode we use a tungsten rod of brand VT-15. The end should be a cone with a small radius.

It is necessary to keep the arc as short as possible. The electrode should come forward from the burner not more than 3-5 mm. The end of the addition wire should not stick from under the protection

of argon, since during fusion oxides get in the melted bath and are dissolved in titanium.

Addition wire or rods have to have a chemical composition, close to the chemical composition of the basic metal. If it is necessary to obtain more plastic fused metal, one should use a wire VT-1D. In the presence of strengthening of seam, destruction occurs with respect to the basic metal, even during welding of highly durable materials, such as alloy VT-6.

Welding by a tungsten electrode of butt joints of titanium alloys can be done on a lining with application of addition wire and without it.

The lining (Fig. 30) is prepared from copper or from stainless steel. For protection from oxidation of the reverse side of the seam, in the linings it is necessary to pass argon for protection of the reverse side of seam; for this purpose holes are provided in the lining. The welded edges must be pressed tightly against the lining.

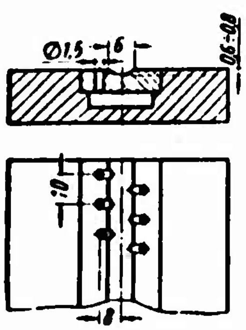


Fig. 30. Construction of lining, applied during welding of titanium alloys.

When making a closing weld in a vessel without a lining it is necessary to feed shielding argon to the reverse side of the seam. Sometimes during welding of vessels made of titanium alloys residual linings are used. However they sometimes lead to lowering of constructive durability from the presence of concentrators of voltages.

During welding of overlap, tee and corner joints it is necessary to pass argon also from the side, opposite to the seam. For this purpose a pipe is put in the corner (copper or stainless steel) with holes from one side (Fig. 31), into

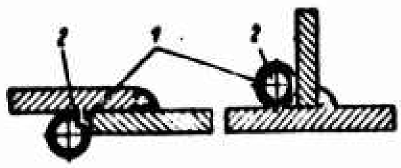


Fig. 31. Protection of reverse side of seam during welding of tee, overlap and corner seams: 1 — tube with holes; 2 — argon.

which moves the argon (4-6 liter/min); emerging through the hole in the pipe, it protects the heated titanium from oxidation.

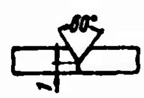
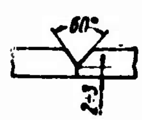
Application of addition wire allows increase in allowances on displacement and gaps approximately by 2 times. During manufacture from titanium alloys of vessels or other units with thickness of wall 4 mm and more it is possible to use combined welding, i.e., the first seam is welded to the canopy without additions, subsequent — argon arc welding by tungsten electrode with addition or automatic welding under flux; the last variant is cheapest. During combined welding the constructive durability is somewhat increased.

During multilayer welding before imposition of every subsequent seam the surface of the preceding should be thoroughly purified from oxides and other compounds. Normal welded seams should have brilliant or slightly oxidized surfaces with golden, blue, violet or pink nuances. Dark-gray color of the seam and, especially, the presence of a white deposit on its surface indicates insufficient protection of the seam from oxidation.

For prevention of appearance with time of cold cracks the welded units or parts no later than 10-15 days after welding have to be subjected to heat treatment at a temperature of 650° for 1 hour.

In welded constructions made of titanium alloys it is possible to use different welded joints: butt, overlap, tee and corner. Preparations of edges under welding and conditions of welding of butt joints are shown in Table 33.

Table 33. Preparation of Edges Under Welding and Tentative Conditions of Argon Arc Welding by Tungsten Electrode of Titanium Alloys Butt-to-Butt

Welding	Form of edges	Thickness of material in mm	Number of layers	Diameter of tungsten electrode in mm	Diameter of addition wire in mm	Current in a	Speed of welding in m/hr	Speed of supply of wire in m/mm	Expenditure of argon in liters/hr
Mechanized without addition		1.5 2 3	1 1 1	2 2.5 3	— — —	120—130 140—150 250—2[illegible]0	20 20 16	— — —	11—13 11—13 11—13
Automatic with addition		1.5 2 3	1 1 1	2.5 2.5 3	1 1 1.6	210—220 220—240 270—280	20 20 18	1.4—1.6 1.6—1.8 1.1—1.3	11—13 11—13 11—13
Manual		5	2	2.5	—	190—210	—	—	11—13
Combined first layer — mechanized second layer — automatic		8	2	3	2.5—3	390—395 300—320	10	—	8—10

For removal of cinder from the surface of welded edges of a part it is first subjected to sand-blast treatment, and then etching in a bath of the following composition:

Acid salt technical....	300-350	m/liter
Acid nitric technical..	55-65	m/liter
Sodium fluoride technical 1 sort.........	40-50	g/liter

The temperature of the bath is 20°C; time of etching 3-10 min depending on the state of the surface and dimensions of the part. According to exhaustion of the solution and accumulation in it of

Table 34. Mechanical Properties of Welded Butt Joints of Titanium Alloys, Carried Out by Argon Arc Welding by a Tungsten Electrode. Thickness 1.5 mm

Brand of alloy	Mechanical properties basic material*		Mean values of mechanical properties of welded joints	
	Ultimate strength in kg/mm^2	Mean values of angle of bend in degrees	Ultimate strength (welding with strengthening) in kg/mm^2	Angle of bend in degrees
VT-1	45-60	180	63.5	93
VT-5	70-95	57	95.1	57
VT-5-1	75-95	69	86.9	76
OT-4	70-90	92	85.4	58
VT-6	90-100	47	100.7	35
IRM-2	90-97	46	90.5	56

*According to technical conditions.

compounds of titanium it is allowed to heat the bath to 50-60°C and to increase the time of holding. After etching of the part, it is washed in hot water, then dried.

Mechanical properties of welded butt joints are given in Table 34.

Welding of steel. Argon arc welding by a tungsten electrode allows joining of sheets in thickness to tenths of a millimeter. Welding may be done in suspension with full melting which allows refusal of application of remaining linings during welding of locking seams in different vessels. This has especially large value during manufacture of high pressure vessels from highly durable materials.

The great merit of argon arc welding is the fact that in the process of welding slag will not be formed. Brands of wire recommended during welding of certain steel, are given in Table 35.

The reverse side of a longitudinal seam is protected by a detachable lining with grooves. Argon gets in the groove from above through gaps end to end (inevitable during welding of real units). If such

Table 35. Brands of Welding Wires, Recommended During Argon Arc Welding of Certain Steel

Brand of welded steels	Recommended brands of wires	GOST or TU
08KP, 10, 20, 25, 15G1A, 12G2A	Sv-08GS, Sv-10GSMT	GOST 2246-60
25KhGSA and 30KhGSA	Sv-18KhGSA, Sv-18KhMA	The same
1Kh18N9T	Sv-04Kh19N9, Sv-06Kh19N9T, Sv-04Kh19N11M3	The same
EI662	Sv-10Kh11VMFN	The same
EI712	Sv-18KhMA	The same
EI654	EI654	ChMTU 5216-55
EI659	Sv-18KhMA	GOST 2246-60

protection is lacking, then the argon pass into the groove through holes made in the lining. Annular seams of the vessels are protected by filling them with argon or nitrogen.

Welding of longitudinal seams must be done in clamp attachments.

Welding by nonconsumable electrodes can be produced on direct current of straight polarity and on alternating current. However burning of arc in the last case is unstable. Furthermore, during welding on alternating current in the arc there appears a component of direct current, complicating the electrical feed circuit.

In order to ensure stable burning of the arc during welding by direct current, it is necessary to use as the electrode a tungsten rod with oxide of thorium of brand VT-15 or a VT-10 of the Moscow electrode plant (normal NIO 021612).

Wide application in industry is found by mechanized argon arc welding of steel without supply of addition wire. The weld will be formed at the expense of melting of the welded edges.

Automatic argon arc welding with supply in the arc of an addition wire allows increase of allowed gaps end to end approximately by 2 times. This method of welding is recommended also for overlap, tee and corner seams.

Manual welding is applied for short seams, annular seams of small diameter, for assembling and in hardly accessible places.

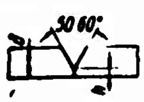
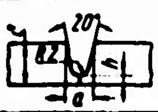
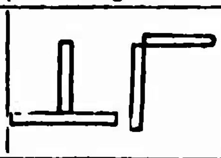
End-to-end butt joints with observance of allowances for gaps and displacement of edges ensure high durability. Overlap joining without addition is applied in small-loaded units or parts. Gap between sheets in overlap does not have to be more than 0.1 mm. Tentative conditions of argon arc mechanized welding of butt joints by a tungsten electrode without additions are given in Table 36, and recommended types of joints, in Table 37.

Table 36. Tentative Conditions of Argon Arc Mechanized Welding of Steel Using a Tungsten Electrode with Direct Current of Direct Polarity

Thickness of material in mm	Diameter of tungsten electrode in mm	Welding current* in a	Speed of welding in m/hr	Expenditure of welding in liters per min
0.5	1	15	28.5	7
1	1-1.5	75	28.5	8
1.5	1.5-2	90-100	19	8
2	2.3	115-120	12	9
2.5	3	150-160	13	9
3.0	4	165-170	13	9
3.5	4	180-190	13	11
5.0	5	260-270	11	11

*During welding with supply of addition wire the current increases by 10-20%.

Table 37. Types of Joints for Argon Arc Welding of Steel

Thickness of material	Form of preparation of edges	Dimensions in mm	
		a	*h*
≤ 1.5		–	2.–2.5δ
≤ 4		≤ 0.15δ	–
≤ 4		–	–
≤ 3		–	–
≥ 4		–	2–3
≥ 10		9–10	2–3
			

Coefficients of durability of welded joints with respect to lower limit of strength of basic metal by GOST or Technical conditions during argon arc welding with a nonconsumable electrode are given in Table 38.

Welding by a consumable electrode is done on direct current of reverse polarity. Recommended electrode wires are shown in Table 35. During welding by a consumable electrode the height of the seam is obtained somewhat larger. As a result of this there may be a sharp transition from fused metal to basic which is undesirable, especially during cyclical loads.

For improvement of forming of the shaft during welding by a consumable electrode in the argon is added up to 5% pure oxygen, which increases the fluidity of the metal of the bath. Addition to the argon of carbon dioxide in quantity 1-2% also promotes obtaining of correct form of seam. During welding in helium the form of the weld is obtained correctly.

For welding of butt joints with full melting from the reverse side it is necessary to have a detachable lining with groove (see Fig. 26) or a residual lining which is less desirable. The protrusion of electrode wire from the neck should be on the average near 10 mm. Surfaces of the welded edges have to be clean, for which a part before

Table 38. Coefficient of Durability of Steel Welded Joints During Welding by a Tungsten Electrode (Strengthening of Weld Is Not Cut)

Method of welding	Durability coefficient
Mechanized without addition	0.85-0.90
Automatic with addition	0.90-0.95

welding is subject to etching, sand-blast treatment or degreasing. For multilayer welding it is necessary that the surface of every layer be cleaned by a metallic brush.

During welding by a consumable electrode are applied two methods: hose semiautomatic and automatic. Tentative conditions of welding of butt joints by a consumable electrode in a stream of argon for steel are given in Table 39.

Table 39. Tentative Conditions of Welding of Butt Joints of Steel by a Consumable Electrode in Argon

Method of welding	Division of edges	Thickness of material in mm	Number of layers	Diameter of electrode wire in mm	Current in a	Speed of welding in m/hr	Expenditure of argon in liters per min
Automatic	Without division	2.5 3 4	1	1.6-2	190-270 220-320 240-330	20-40	6-8 6-8 7-9
	Y-shaped	6 8 10	2	1.6-2	250-350 300-400 340-450	15-20	9-12 11-15 12-17
Hose semi-automatic	Without division	2.5 3 4	1	1 1-1.6 1-1.6	140-180 150-260 180-300	6-7	6-8 6-8 7-9
	Y-shaped	6 8 10	1-2 2 2	1.6-2 1.6 1.6-2	220-320 320-360 290-380	6-7	9-12 11-15 12-17

In end-to-end butt joints, local gaps and displacement by height of welded edges may not exceed 15-20% the thickness of the sheets.

In connection with the appearance of a method of welding in carbon dioxide welding of steel in a stream of inert gases by a consumable electrode in a number of cases is inexpedient.

Welding of copper and its alloys. During welding of copper certain difficulties appear, caused by its great thermal conduction, large affinity of it in liquid state for oxygen and significant solubility in it of hydrogen at high temperatures. Due to great thermal conduction of copper the speed of cooling of the molten metal of the bath is high, and gases, not reaching the surface, create porosity in the fused metal.

Oxygen with cuprous oxide will form a eutectic with temperature of fusing lower than copper (1065°C). During cooling of a metal the eutectic congeals later than the solid solution and serves as a cause of appearance in the fused metal of hot cracks.

Dissolved hydrogen in copper in the presence of cuprous oxide evokes the formation of water vapor, which creates great pressure, evoking cracks. Decreasing the speed of cooling of the molten metal is possible by means of preliminary preheating before welding of the edges or the entire article. Protection of the metal from the influence of oxygen and hydrogen is attained during welding in a stream of inert gases of high cleanness.

Welding of copper in a stream of inert gases is produced in direct current of straight polarity.

For argon arc welding one should recommend well deoxidized copper and its alloys. In this case seams are obtained which are tight with good mechanical properties [32]. The limit of strength

of the welded butt joint is 21-25 kg/mm^2. As addition material is recommended wire with a content of copper of 99% and with additives of silicon, tin and manganese. Welding of butt joints is realized on a copper lining.

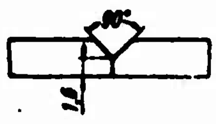
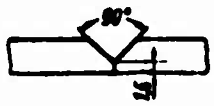
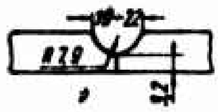
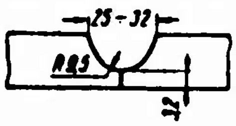
Nickel and silicon improve the weldability of copper; aluminum, berilium, zirconium and titanium – worsen it [31]. Preparation of edges for butt joints with thickness of 12 mm is Y-shaped and for large thickness U-shaped. Approximate conditions of argon arc welding of deoxidized copper are given in Table 40.

Table 40. Conditions for Argon Arc Welding of Copper by Tungsten electrode [31]

Thickness of material in mm	Diameter of electrode in mm	Diameter of addition wire in mm	Current in a	Expenditure of argon in liters/min	Type of joining
1.6	2.4-3.2	2.4	80-110	2.8-3.3	Butt-to-butt without bevel of edges
3.2	2.4-3.2	3.2	140-220	3.3-3.8	The same
4.8	3.2	4.0-4.8	300-400	3.8-5.6	The same, but with gap or bevel
3.2	3.2	3.2	200	6	The same
6.4	4.8	4.8	300	7	Butt-to-butt with bevel of edges
9.6	4.8	4.8	350	7	The same
12.7	4.8	6.4	400	8	The same
16.0	4.8	6.4	400	8	The same

Best results were obtained during welding of deoxidized copper in a medium of helium [32]. Preparation of edges and conditions of welding in a stream of helium are given in Table 41. Welding was

Table 41. Preparation of Edges and Conditions of Welding of Copper in a Stream of Helium [32]

Thickness of material in mm	Division of edges	Number of layers	Diameter of electrode in mm	Diameter of addition wire in mm	Current in a	Arc voltage in v	Expenditure of helium in l/min
0.8–2.4		2	3.2	1.6–3.2	180–220	22–24	10
3.2–5.5		2	4.8	4.8	240–280	22–24	10
6.4–9.5		2	4.8	4.8	380–440	24–26	12
12.6		3	4.8	4.8 (1st layer) 6.4 (2nd and 3rd layer)	490–520	24–26	12
16–19		5	4.8	4.8 (1st layer) 6.4 (others)	480–520	24–26	12
22.2–32		6–8	4.8	The same	480–520	24–26	12

produced on straight polarity. Protection of reverse side of seam was carried out by a copper lining with groove of depth 0.8 mm and width 6.4 mm.

During welding of siliceous bronze as an addition material is recommended wire, close in chemical composition to the basic metal.

Seams with strengthening are equidurable with the basic metal, with removed strengthening; their durability constitutes 80-85% of the durability of the basic metal.

Welding of active metals. During the last few years both at home and abroad the necessity has arisen of welding of active and refractory metals, such as: molybdenum, tungsten, titanium, niobium, zirconium and others. The majority of these metals during heating very energetically interact with oxygen, nitrogen, hydrogen, carbon

and other elements. Oxides and nitrides of these elements significantly change mechanical properties of active metals. Thus, the presence in molybdenum of insignificant quantities of oxygen sharply lowers its plastic properties [33]. During welding of active metals very good protection of the molten and heated metal from interaction with air is required.

During argon arc welding, applying additional protection of metal with the help of shanks and from the reverse side of the seam, manages to obtain good results only during welding of tantalum [34] and niobium. Welding of other metals requires more reliable protection.

More reliable protection is attained during welding in chambers with controlled atmosphere [34], which are filled with inert gases — argon or helium.

During welding in chambers with controlled atmosphere good mechanical properties can be obtained for welded joints from such metals, as zirconium, niobium, and satisfactory ones for welding of molybdenum, if the basic metal has good mechanical properties.

Best results in welding of active and refractory metals is endured by welding using an electronic beam in a vacuum [34].

GAS WELDING BY FUSING

Gas Welding

The process of gas welding is based on using for heating of the metal a high-temperature flame.

Gas welding widely is applied in different branches of industry for manufacture of articles from low-carbon and alloy steel of small thicknesses, thin-walled pipelines, articles from deformed nonferrous

Table 42. Characteristics of Combustible Gases

Fuel	Specific gravity in kg/m^3	Lowest calorific value		Temperature of welding flame in °C	Quantity of oxygen per 1 m^3 of fuel in m^3	
		in cal/m^3	in cal/kg		For full combustion	For welding
Acetylene	1.17	13500	11500	3100	2.5	1-1.1
Hydrogen	0.09	2570	28800	2100	0.5	0.25
Propane	2.0	22100	11000	2050	5.0	2-2.5
Butane	2.7	29500	11000	2050	6.5	2.5-3
Natural gases	0.75	8300	9700	1900	2.0	1
Petroleum gases ...	0.45-0.6	3800-4500	7500-8800	2000	1.0	0.6
Coke gases	0.7-1.5	10500-14500	9500-1600	2100-2300	2-2.5	1
City gases	0.8-1.1	3200-6500	4000-6000	1900	1.2-1.6	0.6-0.8
Benzene, kerosene .	0.7; 0.8*	—	10000	2300	2.4**	1.3-1.5**

*In kg/liter.

**In m^3/kg.

metals, for repair of cast parts from cast iron, bronze, aluminum and magnesium alloys and others.

Gas welding differs preferentially from other methods of welding by fusing by simple equipment, with one set of which it is possible to execute different operations; the possibility of carrying out during welding of cast iron and nonferrous metals, necessary additional heating; good controllability in the process of heating and melting of metal, facilitating joining of thin-sheet and tubular elements of articles; good forming of welded seam.

Deficiencies of gas welding are: large zone of heating up of basic metal and in connection with this relatively significant deformations of elements of joining; overheating and growth of grain in welded joint; smaller productivity and economy as compared to electric arc welding.

On application of an acetyleneoxygen flame is based a number of related gas welding processes: gaspressing welding, oxygen cutting, hard-facing by gas flame.

Gases and Equipment for Welding

As a combustible gas most frequently acetylene is used. Sometimes instead of acetylene other combustible gases (Table 42) are used. The highest temperature of a gas-welding flame is attained during burning of combustible gas in mixture with technical oxygen. During use of atmospheric oxygen the temperature of the gas flame does not exceed 1800-2000°C, whereas for welding of the majority of metals the temperature of the gas flame should be not lower than 3000°C.

Oxygen. Gasiform technical oxygen is supplied by GOST 5583-50 in two sorts: sort A with cleanness 99.2% and sort B with cleanness

98.5%. Oxygen is transported to the consumer in a compressed state in bottles (GOST 949-57) or in liquified form in transport tanks. The most wide-spread are bottles of capacity 40 liters, containing at a pressure of 150 atg,* 6 m^3 of oxygen. Liquid oxygen is used with the help of gasificators for central feed. Gasificators contain 1000 liters of liquid oxygen and give nearly 800 m^3 gas. Oxygen in bottles is more convenient, but transport expenditures are increased. On location oxygen moves in the gaseous state by pipelines and hoses.

Acetylene is obtained from calcium carbide on interaction with water (Table 43). Calcium carbide is supplied in hermetically closed steel drums weighing 50-130 kilograms.

Table 43. Yield of Acetylence in Liters from 1 kg Calcium Carbide of Different Granulation (by GOST 1460-56)

Dimensions of pieces of calcium carbide in mm	Yield of acetylene in 1	
	First sort	Second sort
2 x 8	255	235
8 x 15	265	245
15 x 25	275	255
25 x 80	285	265

For obtaining of acetylene acetylene gas producers (Table 44) are used. They are distinguished: by productivity, pressure (low pressure — to 0.1 kg/cm^2, average — from 0.1 to 1.5 kg/cm^2, high — over 1.5 kg/cm^2); kind of installations (mobile and stationary); principle of operation (generators of the system "carbide in water," "water in carbide" with variants of wet and dry process and generators of a contact system with variants of displacing of water and submersion of carbide).

Acetylene can be supplied in acetylene bottles (GOST 5948-51), filled by a porous mass (activated carbon), impregnated with acetone.

*atg = atm (gage).

Table 44. Exploitationally-Technical Characteristics of Acetylene Gas Producers

Type of generator	Nominal productivity in m^3/hr	Biggest pressure in body in atm	Operating pressure on getting out of water lock in atg	Applied granulations of carbide in mm	Load of carbide in kg	Height of generator in mm	Dimensions in plan or diameter of body in mm	Weight of generator in kg	
								Without water and carbide	In charged state
ASS-3-55....	80	1.5	0.6-0.7	Any	450	4200	Length 3370	—	—
"Autogen-M".	50	0.7	0.3-0.5	Any	120	2700	1500	1300	—
GND-35......	35	0.05	0.025	From 8/15 to 25/80	160-200	3800	1400	—	—
ASR-1-56....	20	1.5	0.5-0.8	15/25 and 25/80	80	1430	1050 x 2700	1860	—
GRK-10-57...	10	1.5	To 0.7	25/80	20-25	2100	1400 x 1320	650	—
GVR-3.......	3	0.7	0.15-0.3	25/80	8	1260	630	110	220
MG-54.......	2	0.10	0.030	15/25 and 25/80	5	1170	590	70	270
GVR-1.25M...	1.25	0.7	0.08-0.15	25/80	4	1042	480	54	110
ANV-1.25....	1.25	0.1	0.025-0.030	25/80	4	1120	446	42	130
ASM-1-58....	1.25	1.5	0.1-0.3	25/80	2.2	795	295	20.4	37

Bottles filled with acetylene are under a pressure of 16 atg. Bottles with a capacity of 40 liters under a pressure of 16 kg/cm^2 contain 4-5 m^3 of acetylene.

Other combustible gases. Besides acetylene, for welding of metals (besides steel and copper) it is possible to use other combustible gases (benezene, propane, butane, hydrogen, petroleum and natural gases).

Combustible gases can form with air and oxygen explosive mixtures.

Table 45. Technical Characteristics and Dimensions of Safety Liquid Locks of Closed Type

Parameters	Brand of valve				
	ZSB-58	ZSD-3-07	VZSD-10	ZSB-1-57	VZSD-35
Maximum carrying capacity in m^3/hr	3.2	3	10	10	35
Biggest permissible operating pressure in atg	0.7	0.7	1.5	1.5	1.5
Loss of pressure during maximum expenditure in atg	0.050	0.045	0.050	0.055	0.15
Quantity of flooded water in liters	1.9	2.1	5.5	5.0	22.0
Basic dimensions of vessel in mm:					
diameter	108	108	152	194	273
height	617	582	800	920	1135

Safety valves (Table 45) are set before points of use of the gas. They protect the acetylene gas producer or acetylene main line from reverse blow of flame from the welding burner or cutter ensuring safety during feeding of the welding posts with acetylene. On the construction and manufacture of safety locks are imposed requirements, presented in GOST 8766-58.

Distributive equipment. For feeding of networks with oxygen and

combustible gas the bottles are joined to oxygen and acetylene ramps. Lowering of pressure of the gas to operating pressure under which it should enter the burner, and also adjustment and supporting of the pressure at the given level is carried out with the help of reductors (Table 46).

Table 46. Technical Characteristic of Reductors (By GOST 6268-59)

Brand	Gas	Biggest inlet pressure in atm	Limits of operating pressure in atg	Biggest carrying capacity in m^3/hr	Additional characteristics
RK-53	Oxygen	150	1-15	60	—
KRR-50	Oxygen	150	5-25	220	Ramp
RKD-8	Oxygen	200	0.5-8	25	Dual chamber
RAR-55	Acetylene	25	0.05-1.5	50	Ramp
RD-2A	Acetylene	25	0.1-1.5	5	—
DAR-55	Acetylene	16	0.05-1.5	5	Reductor-regulator

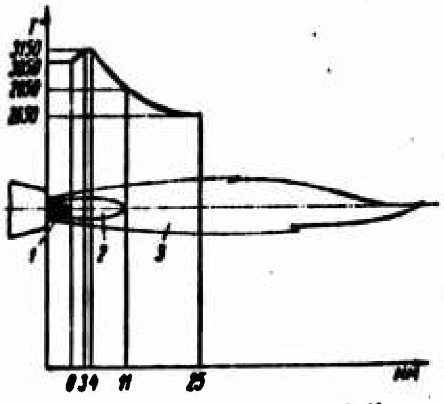
For feed of combustible gases and oxygen to burners rubber hoses are used by GOST 8318-57, calculated on a nominal operating pressure of 10 atg. The widest used are hoses with nominal internal diameter of 9 mm and external 18-22 mm.

Welding burners. Acetylene and oxygen are mixed in needed proportion in a welding burner (Table 47). Fuel mixture, outgoing from the neck of the burner, burns, forming a stable and concentrated high-temperature welding flame (Fig. 32).

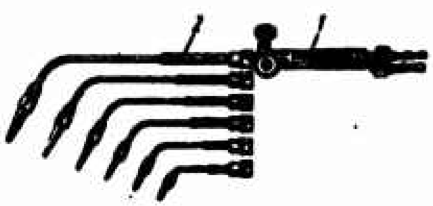
A welding burner (Fig. 33) consists of a barrel 1 and shift tips 2. The latter are distinguished by expenditure of gases and are selected depending upon thickness and dimensions of details and thermal conduction of welded materials.

Table 47. Technical Characteristics of Universal Burners

Type of burner	No. of tip	Approximate thickness of welded steels in mm	Expenditure in liters/hr	
			Acetylene	Oxygen
GS-53 and "Moscow"	1	0.5–1.5	50–125	55–135
	2	1–3	120–240	130–260
	3	2.5–4	230–400	250–430
	4	3.5–7	400–720	430–770
	5	6.5–11	670–1100	720–1200
	6	10–17.5	1030–1750	1150–1975
	7	17–30	1710–2800	1900–3150
GSM-53	0	0.2–0.7	20–65	22–70
	1	0.5–1.5	50–125	55–135
	2	1–3	120–240	130–260
	3	2.5–4	230–400	250–430



·Fig. 32. Diagram of acetyleneoxygen flame and change of temperature of it along the axis: 1 — nucleus; 2 — restoring zone; 3 — torch.



.Fig. 33. Universal welding burner: 1 — barrel; 2 — tip.

The tip of the burner should be such that on every millimeter of thickness of the welded part the expenditure of acetylene is (in liters/hr): for steel 80-120, cast iron 110-140, copper 100-200, brass 130, bronze 100 and aluminum 60-100.

Technology of Welding

Acetylene-oxygen flame. There are three basic forms of flame (Table 48): normal — not provoking oxidation of metal of saturation by it with carbon; oxidizing — for a surplus of oxygen in mixture, provoking oxidation of metal; carburizing — for surplus of acetylene in mixture, provoking transition of carbon from products of flame into the metal.

Usually during welding a normal flame is used; sometimes it is recommended to use a slightly carburizing or slightly oxidizing flame.

Methods of manual welding. Quality of welded joint depends on the adjustment of the flame, which is produced on the basis of appraisal of it externally, angle of inclination of flame to surface of metal (Fig. 34), form of forward-oscillatory movement of burner (Fig. 35), selected method of welding.

Two basic methods of ore gas welding are known: right and left. In the first case the flame of the welding burner is directed towards the seam, the burner shifts ahead of the rod of addition metal,

Table 48. Characteristic of Acetylene-Oxygen Flame

Flame	Ratio O_2:C_2H_2	Temperature in °C	Area of application
Normal	1-1.2	3100	Welding, qualitative cutting and soldering, metallizing
Carburizing ...	0.8-1	2700-3100	Hard-facing of hard alloys. Welding of high-carbon steel
Oxidizing	1.2-1.5	3100-3300	Cutting and soldering, welding of brass and cast iron by bronze, surface hardening, fire purification of surface

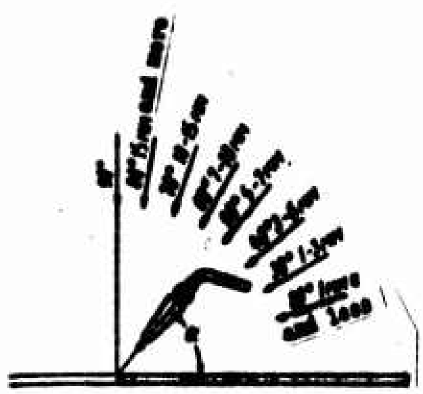


Fig. 34. Angle of inclination of burner.

process of welding is conducted from the left to the right; in the second – the flame is directed to the side of the still not welded joining, ahead is the rod of addition metal, but behind it the flame of the burner, process of welding is conducted from the right to the left.

Left method, obtaining the biggest propagation, is useful for welding of details of different thickness (more productive during welding of steel of thickness to 3 mm), ensures obtaining of seam with uniform width and height of shaft and with best appearance. With this method decreases the probability of burning of the metal during welding of sheets of small thickness.

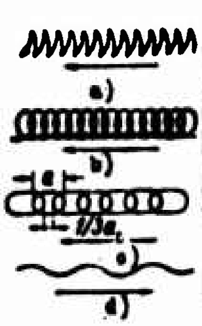


Fig. 35. Kinematics of movement of the burner: a) zigzag-like; b) spiral; c) pivot; d) straight.

Right method is recommended for welding of steel, especially from alloy steel and steel with

heightened content of carbon, parts in thickness more than 5 mm and only in the lower position it differs by larger productivity than the left during welding of steel of thickness more than 5 mm and ensures some heat treatment of the welded joint.

For obtaining of welded seam of good quality with penetration over the entire section, uniform strengthening, smooth transition from strengthening to basic metal it is necessary to produce corresponding preparation of welded edges and to observe given conditions of welding (Table 49).

Types of welded joints. For gas welding joining end-to-end, overlapping, T-connection, corner, and flanging are used.

The flame of a gas burner melts metal to a depth of several millimeters. For obtaining of penetration all over the section on the welded edges bevels are made one-sided and bilateral, the dimensions of which are established depending upon the thickness of material, welded parts, form scene of welded joint, method of welding (right, left). In Table 50 are given forms of preparation of edges under welding in steel parts. In cast parts for correction of defects the method depends on the character of the defect (cranks, unmolded edges, cavities, etc).

Types of welded seams. During welding of steel horizontal, vertical and ceiling seams are used; during welding of nonferrous metals, horizontal.

Welding of horizontal seams in the lower position is the most convenient and productive. Dimensions of seams for steel parts are given in Table 51. In parts made of nonferrous metals, welded seams usually are reinforced.

Table 49. Conditions of Gas Welding

Thickness of welded edges in mm	Form of joinings											
	End-to-end			In brands			Overlapping			By edge		
	No. of tip	Pressure of oxygen in kg/cm^2	Diameter of addition wire in mm	No. of tip	Pressure of oxygen in kg/cm^2	Diameter of addition wire in mm	No. of tip	Pressure of oxygen in kg/cm^2	Diameter of addition wire in mm	No. of tip	Pressure of oxygen in kg/cm^2	Diameter of addition wire in mm
0.5-0.8	0-1	1.5	1.0	0-1	1.5	1.0	0-1	1.5	1.0	0-1	1.5	1.0
1.0-1.5	1-2	1.5-2.0	1-1.5	1-2	1.5-2.0	1.5	1-2	1.5-2.0	1-1.5	1-2	1.5-2.0	1-1.5
1.5-2.0	1-2	2-2.5	1.5-2.0	1-2	2-2.5	1.5-2	1-2	2.0-2.5	1.5-2	1	2	1.5-2
2.0-2.5	2-3	2.5	2.0	2-3	2.5	2.5	2	2.5	2	1-2	2-2.5	2
2.5-3.0	3	3.0	2.5	3	3	2.5	2	2.5-3	2.5	2	2.5-3	2.5

Table 50. Forms of Preparation of Edges for Welding in Steel Parts

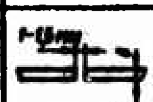
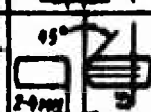
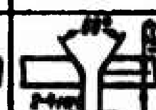
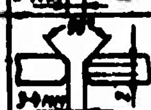
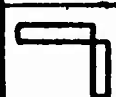
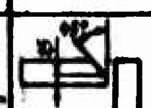
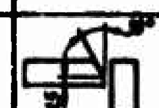
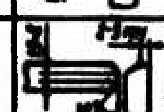
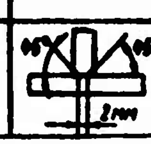
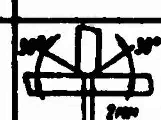
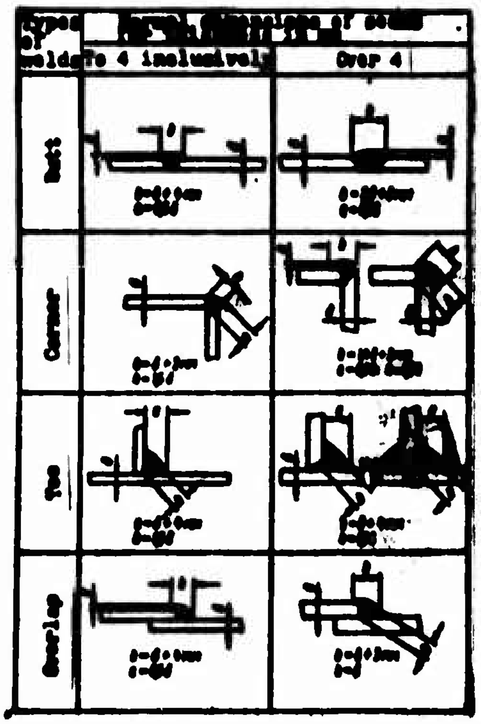
Type of Joints	Thickness and of welded metal in mm	Form of preparation of edges under welding			
		Left		Right	
		One-sided	Bilateral	One-sided	Bilateral
Butt	To 2				
	To 2				
	2-5				
	5-15				
	From above 15				
Corner	To 5				
	5-15				
	From above 15				
Tee	To 3				
	3-15				
	From above 15				

Table 51. Dimensions of Welded Seams



Weldability of Metals

In the process of welding of certain metals and alloys it is possible to have formation of cracks in seams also in the zone of welding. Weldability of metals is influenced by the chemical composition and structure of basic and addition metals, technology of welding, type of construction, complexity of welded units, character of fastening of welded elements.

Low-carbon steel is welded well with a content of carbon to 0.2%, satisfactority – for a content of carbon to 0.35%. Welding (possible in all positions) is produced by a normal flame; basic and addition metal is melted by a restoring zone; the end of the nucleus of the flame is at a distance of 2-3 mm from the surface of metal. Welding wire is selected depending upon the brand of welded steels ana assignment of article (Table 52). Tentative mechanical properties of the fused metal are given in Table 53. Normalization is executed by repeated heating of the welded seam by a welding burner to 930-950°C. Mechanical properties of the welded seams somewhat are improved after forging of them with preheating by the flame of a welding burner to red incandescence and subsequent normalization.

Low-alloy construction steel is welded, as a rule satisfactorily.

On weldability of alloy steels the biggest influence renders the content of carbon. For a content of carbon to 0.2% steel is welded well; for a content of 0.2-0.3%, satisfactorily, slightly carburizing

Table 52. Welding Wire for Welding of Low-Carbon Steel

Welded steel	Welding wire	
	For responsible constructions	For other constructions and articles
St. 0	–	Sv-08 or Sv-15
St. 1, St. 2, St. 3		
St. 4	Sv-08 or Sv-15	Sv-08 or Sv-15
08, 10	Sv-08A	Sv-08
15, 20, 30	Sv-08A or Sv-08GA	Sv-08 or Sv-15
15G, 20G, 30G	Sv-08GA or Sv-15GA	Sv-08G or Sv-15G

Table 53. Mechanical Properties of Fused Metal

Parameters	Wire		
	Sv-08, Sv-08A, Sv-15	Sv-08G, Sv-08GA, Sv-15G	Sv-10GS
Yield point in kg/mm^2............	17-25	20-30	–
Limit of strength in kg/mm^2.........	33-36	33-44	43-48
Elongation per unit length in %..	8-16	8-16	8-16
Shock viscosity in kg/cm^2:			
in initial state	1-4	4-10	5-7
after normalization.........	4-14	8-14	9-14

flame; for a content of 0.3-0.4%, limited under special conditions; for large content of carbon, badly.

Alloy elements do not prevent or assist welding of steel for low content in them of carbon, but namely (in %): <1.5 Mn; <0.8 Si; <0.3 Ni; <1 Cr; <0.6 Mo; <0.3 V; <0.5 W; <0.6 Cu; <0.3 Ti. In large quantity in average and high alloy steels for a content of carbon over 0.25% many of them (Mn, Cr, Ni, Mo, W) increase inclination of steel

to hardening and formation of cracks.

Certain elements (Si, Cr, V, W, Al) with heightened content of them in alloy refractory oxides are formed hampering welding and lowering plasticity of the fused metal.

During welding of alloy steel fluxes are used (Table 54) and wire of corresponding brands (Table 55).

Table 54. Fluxes for Welding of Alloy Steel

Components	Content of Component in Different Fluxes in %							
	No. 1	No. 2	No. 3	No. 4	No. 5	No. 6	No. 7	No. 8*
Drill	—	50	80	50	—	40	—	—
Boric acid	—	50	—	35	—	50	55	—
Dioxide of titanium	—	—	—	15	—	—	5	20
Silicon dioxide	—	—	20	—	—	—	10	—
Bicarbonate of sodium	50	—	—	—	—	—	—	—
Marble	—	—	—	—	—	—	—	28
Fluorspar	—	—	—	—	80	10	5	—
Ferrotitanium	50	—	—	—	—	—	—	—
Ferrochrome	—	—	—	—	20	—	5	6
Ferromanganese	—	—	—	—	—	—	10	—
Carbonate of sodium	—	—	—	—	—	—	10	10
Ferrosilicate	—	—	—	—	—	—	—	6
Porecelain	—	—	—	—	—	—	—	30

*Flux No. 8 is diluted to a 20% solution of soluble glass.

Low-alloy steels NL-1 and NL-2, used in building constructions and chemical apparatus-structure, are welded well at positive temperatures. Welding is executed by a normal flame; as addition metal is used low-carbon wire or wire of the same composition as the welded material. For increase of density of metal of seam forging is expedient

Table 55. Wire for Welding of Alloy Steel

Steel	Brand of steel	Brand of wire
Low-alloy	NL-1, NL-2	Sv-10GS, Sv-15
Chromous	15Kh, 20Kh, 30Kh, 40Kh, 50Kh, 15KhA, 20KhA, 30KhA, 38KhA, 45KhA, 50KhA	Sv-08GA
Chromovanadium	15KhFA, 20KhFA, 40KhFA, 50KhFA	Sv-08GA
Molybdenum	15M, 20M, 30M, 15MA, 20MA, 30MA	Sv-15, Sv-12M, Sv-08GA, SV-12M
Chromiummolybdenum	12KhM, 20KhM, 30KhM, 15KhMA, 20KhMA, 30KhMA, 35KhMA, 36Kh2MA	Sv-08, Sv-12KhM, Sv-08GA, Sv-18KhMA
Chromosilicon	33KhS, 37KhS, 40KhS, 33KhSA, 40KhSA	Sv-15, Sv-10GS
Chrome-manganese-molybdenum	18KhGM, 18KhGMA, 40KhGM, 40KhGMA	Sv-15, Sv-15G, Sv-18KhMA
Silicomanganic	27SG, 35SG	Sv-15, Sv-10GS
Chromosilicomanganic...	20KhGSA, 25KhGS, 25KhGSA, 30KhGS, 30KhGSA, 35KhGS, 35KhGSA	Sv-08A, Sv-18KhGSA, Sv-15, Sv-18KhGSA
Chromoaluminum and chromo-molybdenum-vanadium	30KhYuA, 38KhMYuA, 25KhMFA, 25Kh2MFA	Sv-08A
Nickel	25N, 25NA, 30N, 30NA	Sv-08GA
Nickelmolybdenum	15NM, 15NMA, 20NM, 40NM, 40NMA	Sv-12M, Sv-15
Chrome-nickel	20KhN, 20KhNA, 40KhN, 40KhNA, 50KhN, 12Kh2N2, 12Kh2N2A, 12KhNZ, 12KhNZA, 20KhNZA, 30KhNZ, 30KhNZA, 37KhNZA, 12Kh2N4, 12Kh2N4A, 20Kh2N4, 20Kh2N4A	Sv-15, Sv-08A
Chromolybdenum	12Kh2N3MA, 12Kh2N4MA, 33KhN3MA, 40KhNMA, 30KhN2MFA, 45KhNMFA	Sv-08, Sv-15

at lightly-red incandescence (800-850°C), after which the welded joint is subjected to normalization with heating in a furnace or burner.

Molybdenum and chromo-molybdenum steel (15M, 20M, 30M, 20KhM, 30KhM and others), used for manufacture of pipes is welded by gas welding during assembling of high pressure boilers. Welding is executed with observance of special technological conditions: division of edges at an angle of 45 ± 2.5°; preliminary heating at ambient temperature lower than zero; welding in one layer for thickness to 5 mm and in two layers for larger thickness, etc. During welding of steel 15M by wire of the same brand, ultimate strength of fused metal after normalization of seam by welding burner (heating to 930-950°C) and subsequent cooling in air is approximately equal to 45-47 kg/mm^2, relative lengthening is 13-18%, shock viscosity is 10.6-14.6 $kg{\cdot}m/cm^2$. Chromiummolybdenum pipes are not as easily welded as molybdenum.

Chromosilicomanganic steels 25KhGS, 25KhGSA, 30KhGS, 30KhGSA, 35KhGS are welded satisfactorily; they are used for thickness of elements 0.8-3 mm in joints butt-to-butt for a ratio of thicknesses not more than 1:2, overlapping and T-connection, not more than 1:6 (overlapping and T-connection are not recommended). For welding wire Sv-08, Sa-08A, Sv-15 in articles with required ultimate strength to 90 kg/mm^2 and 20KhGSA, 20KhMA is used if is necessary to have an ultimate strength over 90 kg/mm^2. After welding heat treatment of articles is recommended — normalization or hardening and tempering. Welding is done by normal seam, without flux and preheating at a temperature of environment not lower than +5°. Steel 30KhGSNA is welded badly.

Chromous steels of different brands with small content of carbon

during welding are inclined to formation of cracks. For steels of the ferrite class, containing from 23 to 30% chromium, gas welding is not recommended. Welding of steel, containing 12-14% chromium, is used for articles of thickness 1-3 mm during observance of a number of technological methods, promoting the obtaining of welded seams of good quality (general preliminary heating to 200-250° or heating edges by flame of burner, maximum speed of welding in one passage, capacity of tip of burner 75 liters/hr per millimeter of thickness of article, normal flame with small surplus of acetylene, application of flux). Sometimes it is expedient to use addition wire made of chrome-nickel steels (18-20% Cr, 8-11% Ni). After welding an article should be thermally treated.

Austenitic chrome-nickel steels with small content of carbon (1Kh18N9T, Kh18N11B, Kh18N12M2T and others) are welded well. Welding is used for articles in thickness up to 2 mm. However the welded joint as compared to the basic metal in initial state possesses smaller resistance against intercrystallite corrosion. Welded joints of chrome-nickel steels, subjected to heat treatment (heating to 1050 to 1100°C, fast cooling in water), have satisfactory mechanical properties and resistance against intercrystallite corrosion. For welding flux is used (Table 15), which is put on the reverse side of the joint. The limit of strength of the metal of seam of steel 1Kh18N9T approximately is equal to 47 kg/mm^2, lengthening 10.4%. Austenitic chrome-nickel steels with heightened content of carbon are welded badly.

Cast iron. Welding of cast iron is very effective and depending upon the character of the defect, place of location, assignment, conditions of exploitation and construction of the past (article) it

is done with general, partial or local preliminary preheating of the article or without preheating.

The most successful and qualitative is welded gray cast iron, having in the break fine-grained structure of light-gray color. Improvement of workability of hard-facing promotes the application of flux (Table 56). Cast iron of dark-gray color in the break with big grains is welded significantly worse. Hard to weld is cast iron with a large quantity of graphite. It is not possible to weld burned cast iron, working at high temperatures in contact with gases for a long time. In a number of cases good results are attained during welding of cast iron by brass rods of composition in %; 60-63 Cu; 0.4-0.6 Sn; 0.3-0.4 Si; remaining Zn. The necessity of preheating is often dropped in this process.

Increase in durability of joints promotes different auxiliary measures — setting of pins, foundation laying of anchors, special division of edges and others.

Welding of alloy cast iron, containing nickel, chromium, copper and other impurities, is done by the usual method. In this it is expedient to apply addition metal of the same chemical composition as the basic metal.

Red copper is welded well. After forging (at a temperature of 200-300°) durability of fused metal is 17-22 kg/mm^2.

For welding of articles at a thickness of 1-2 mm as addition metal we use wire of diameter 2-8 mm made of electrolytic copper; at a thickness of 3-10 mm, copper wire with addition 0.2% phosphorus; higher than 10 mm, copper wire, containing 0.2% phosphorus and 0.15-0.30% silicon. For deoxidation and destruction of cuprous oxide during welding fluxes and plastering (Table 56) are used. Annealing after welding and subsequent cooling give copper the necessary plasticity.

Table 56. Composition of Fluxes

Welded metal	Content in %			
	Borax decahydrate	Borax anhydrons	Silica	Other additives
Stainless steel	—	67	32.6	Ferrochrome 0.15 Ferromanganese 0.25
Case iron	100 50	— —	— 3	 Sodium bicarbonate 47
Copper, brass, and bronze	—	70	—	Boric acid 10 Sodium chloride 20

Brass is welded well with a content of zinc to 39%. Usually a part is welded of small thickness; for thick-walled articles flux (Table 56) is used. Durability of the welded joints for small thicknesses is 90-95% of the durability of the basic metal. High mechanical properties of welded seams and relatively large density are attained during use as addition metal of alloy rods instead of brass. For welding with addition wire LK62-0.5 as a flux we use a dehydrated drill (in the form of powder or paste).

Mechanical properties of welded joints essentially are lowered with increase of thickness of the welded sheets (Table 57). During welding significant deformations of articles are possible which are removed by dressing.

Heat treatment after welding of parts in thickness to 3 mm is not needed; a part of large thickness is recommended to heat to 550-600°C and then slowly to cool.

Bronze. Chromous bronzes have best weldability. Stannous bronze

Table 57. Mechanical Properties of Welded Joints of Brass L62

Thickness of metal in mm	Brand of addition wire	Mechanical properties of joints	
		Ultimate strength in kg/mm^2	Angle of bend in degrees
3	L62	33.9	180
11	L62	23.8	135
3	LOK59-1-0.3	37.2	180
4	LK62-0.5	40.4	180

is welded well with a content of tin to 7%. For larger content we need heating before welding and slow cooling.

Siliceous and manganese bronzes weld well; welded seams possess high mechanical properties.

For welding of foundry bronze for the prevention of formation of cracks from internal stresses it is recommended preliminarily to heat the part to 450°C. After welding cast parts of stannous or low silicon bronze are annealed at 450-500°C with subsequent cooling in water. During welding of rolled bronze it is possible to use forging. The limits of strength of metal of the weld of bronze attains 30 kg/mm^2.

Aluminum deformed alloys of different brands are widely used in welded articles. Alloys of type AMts (1-1.6% Mn) and AMg (2-6% Mg) are welded well. As addition material we use strips, cut from welded sheets or wire of brand AK. Application of the latter certainly is obligatory during welding of specially tense details.

Ultimate strength of metal of the seam of aluminum alloys is 8-11 kg/mm^2, angle of bend 110-180°.

In parts made of technical aluminum or from alloy AMts is allowed forging of welded seams in the cold state. Forging of seams in parts made of other alloys is not recommended. Holes, closely located to seams, should be drilled after welding.

Welding of details usually is done outside the attachment and,

as a rule, in the lower position. In special cases welding is allowed in slanted and vertical positions. Ceiling welding is prohibited. Parts with thickness of walls more than 5 mm are welded with preheating to 300-350°C, which usually is done by a gas burner.

During welding of aluminum alloys flux of brand AF-4A isolated in water is used which is applied by dipping in addition material and when necessary brushing a film on the reverse side of the welded edges. After welding, but not later than 6 hours, the flux thoroughly must be removed by washing (consecutively in three baths: in hot water, in chrome anhydride, in hot water), and the part dried in a drying cabinet at a temperature of 110-180°C to fully remove all traces of moisture.

Welding by flame with surplus of oxygen is not allowed. Angle of inclination of burner to surface of welded part should be 30-45° for a thickness of material of 5 mm and 45-60° for large thickness. Etching of parts after welding is permitted only with 100% penetration of the edges.

Welding of aluminum castings of different brands, applied for correction of foundry defects (surface and transverse unmolded edges and gas cavities, incomplete and displaced bosses, cracks, pinchers and shear drags, mechanical failures during finishing of the casting, slag cavities), is conducted with preliminary preheating in furnaces to 350-390°C and use of addition metal in the form of rods by diameter 5-10 mm, poured from modified Silumin and flux of brand AF-4A.

After welding of defects castings are immediately subjected to heat treatment (annealing at a temperature of 300-350° with holding for 2-5 hours) for removal of internal stress and obtaining of fine-grained structure of seam. After heat treatment the castings are

cleaned of remainders of slag and flux (washing in baths or with brushes and hot water and a solution of chrome anhydride) and died in hot air to fully remove all traces of moisture.

Magnesium alloys (deformed) brands MA-1, MA-2, MA-8 possess satisfactory weldability, which depends on the content in them of manganese and zinc. Alloys, containing large quantity of manganese, are welded badly. Alloys with high content of zinc are inclined to formation of cracks in the process of welding. T-connections, overlapping, corners are not recommended. During welding fluoride fluxes are used and addition material (wire, rods, stripe) from alloys of brands MA-1 and MA-2.

Parts are welded, in which are permissible remainders of flux. Flux and slag are removed immediately after welding (but not later than after 3 hours) by soft steel brushes or by steam blast cleaning with worked sand.

Durability of welded joints is 65-80% of the durability of the basic material.

Welding is produced by normal flame the nucleus of which is located at a distance of 3-5 mm from the molten metal, with an angle of slope of burner of 30-45° outside attachments with preliminary preheating to 300-350°C (for a thickness of walls more than 5 mm) in the lower position by the left method with thickness of part to 5 mm and right for larger thickness. Etching of details after welding is not allowed.

Foundry magnesium alloys of different brands. Before welding of defects (unmolded edges, gas cavities, mechanical damages, cracks, displaced boss) the casting is heated in a furnace to 350-400°C for not less than 4 hours. During welding, addition metal is used in

the form of rods of diameter 5-8 mm poured from alloy of the same brand, as the basic metal, and a fluroide flux. After welding the part is immediately subjected to annealing at a temperature of 200-250°C and purification from remainders of flux and slag.

Nickel is welded satisfactorily. As addition metal we use strips of basic metal or wire of the same composition. Welded joints of Nichrome have a limiting strength of 35-45 kg/mm^2.

Lead is welded by hydrogen-oxygen, acetyleneair and acetylene-oxygen flame. For great thickness of welded articles multilayer welding is used. Welding may be done in the lower, vertical and ceiling position of seam. As addition metal we use lead wire.

Zinc is welded, observing special safe conditions of work (in connection with singling out of poisonous vapors). As addition metal use zinc wire.

Technological Indices of Welding

The capacity of the welding flame M is measured by expenditure of gas in liters/hr, i.e.,

$$M = W/t = C\delta,$$

Where W is the quantity of fuel in liters; t is the time of welding in hours; δ is the thickness of welded parts; C is the coefficient, the values of which for welding of parts in thickness from 1 to 15 mm are given in Table 58.

Speed of welding

$$v = K/\delta \text{ m/hr}.$$

Coefficient K is experimentally also assumed equal during welding of steel to 10-15, copper 24, brass 12, aluminum 30, cast iron 10, stainless steel 10.

Table 58. Values of Coefficient C

Joint	Low-carbon steel	Alloy steel, cast iron	Copper	Copper alloys	Aluminum
Butt......	100	80	130-180	75-85	110-130
Overlap...	140	110	180-250	100-110	150-180
Tee.......	150	120	200-300	100-120	160-200
Corner....	80	70	110-150	70-80	100-120

Time of welding. The technical time (basic + auxiliary)

$$t = d\delta \text{ min/m.}$$

The values of the coefficient d depending upon the welded metal are recommended as follows:

Low-carbon steel 5-4
Alloy steel, cast iron, copper alloys 6
Copper 3.5
Aluminum 4

Expenditure of materials. For average conditions of welding on 1 running meter of seam is expended in liters:

Acetylene .... $8\delta^2$

Oxygen .... $9.5\delta^2$

Expenditure of addition wire on welding of 1 running meter of seam, one can determine by the formula

$$P = C\delta^2 \text{ gram/running meter}$$

where C is the coefficient, the values of which for different metals are given in Table 59.

Table 59. Values of Coefficient C

Metal	δ in mm	Preparation of seam	Coefficient C
Steel	<5	Without bevel	12
	≥5	Bevel 45°	10
		" 35°	8
		" 30°	7
Copper	<4	Without bevel	18
	≥4	Bevel 45°	14
Brass	<4	Without bevel	16
	≥4	Bevel 45°	13
Aluminum	<4	Without bevel	6.5
	≥4	Bevel 45°	4.5

Hard-Facing

Cast hard alloys (VK3, sormite No. 1 and No. 2) are fused onto a mechanically treated surface; height of hard-facing is 1.5-2.5 mm. Before hard-facing, blanks are heated in furnace or burner to 400-500°C.

The capacity of the burner is selected depending upon the thickness of the article; hard-facing is produced by flame with small surplus of acetylene; as flux is used fused borax.

After hard-facing the article is slowly cooled together with the furnace or in sand; parts, fused by alloys VK3 and sormite No. 1 are not subjected to heat treatment; articles, fused by alloy sormite No. 2, are annealed and after machining subjected to hardening with tempering (heating to 850-860°C, cooling in oil and then heating to 500-550°C and cooling in air).

Granular or powdery hard alloys are mixed with 5-6% remelted drills and steel thin-walled pipes are filled by them (diameter 4-8 mm,

length 300-500 mm; for manufacture of pipes may be used sheet steel of thickness 0.6-1 mm), which is used as addition metal during hard-facing. Hard-facing is executed just as for poured hard alloys. Articles, fused by powdery hard alloys, are not subjected to heat treatment.

Automatic Gas Welding

Automatic gas welding obtained the biggest application during manufacture of thin-walled pipes from blanks in the form of strips. For this purpose are used special machines, in which is done the molding of the pipe blank, welding and other operations up to full manufacture of a pipe of given length. The speed of welding reaches 500-2000 m/hr. Application of automatic welding for analogous conditions of welding is possible.

WELDING BY PRESSURE

Contact Electric Welding

Basic methods of contact welding are classified according to Fig. 36.

Machines for contact welding usually are supplied with single-phase transformers, a feeding welding circuit with large current for low voltage and included in a three-phase 50 cycle circuit with non-uniform load of phases. During welding of longitudinal seams of pipes from steel and nonferrous metals we successfully use current of frequency to 450,000 cps.

Welding by impulse of direct current is used for joining of parts of relatively great thickness made of light alloys during point and roller (step) welding. In addition, the primary winding of the

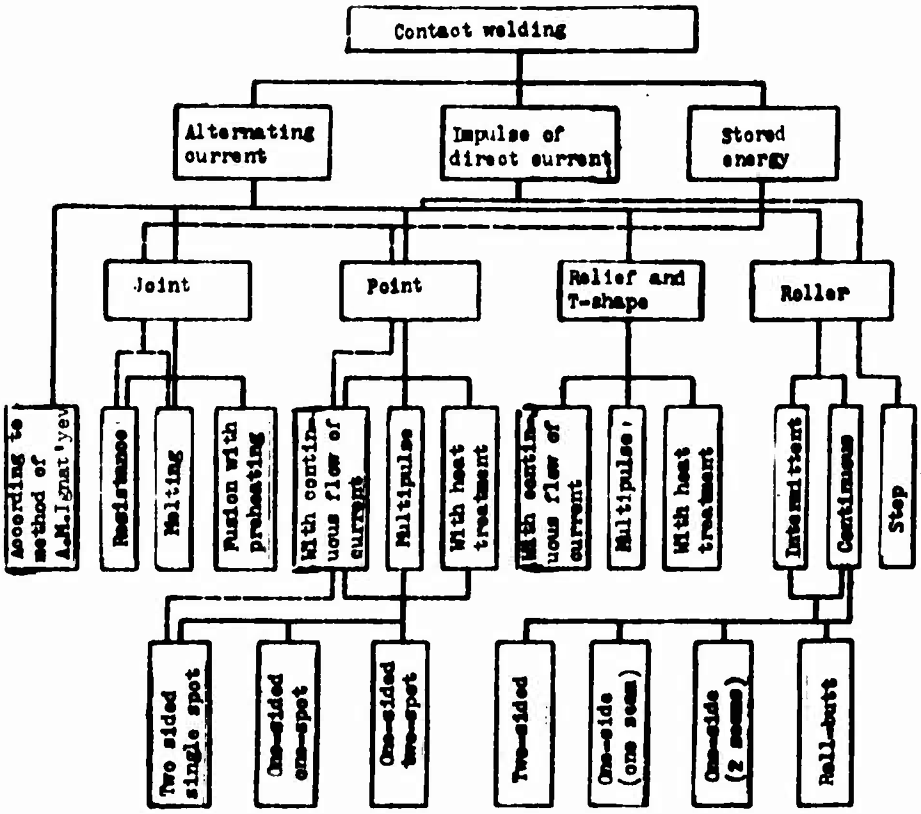


Fig. 36. Classificational diagram of basic processes of contact electric welding.

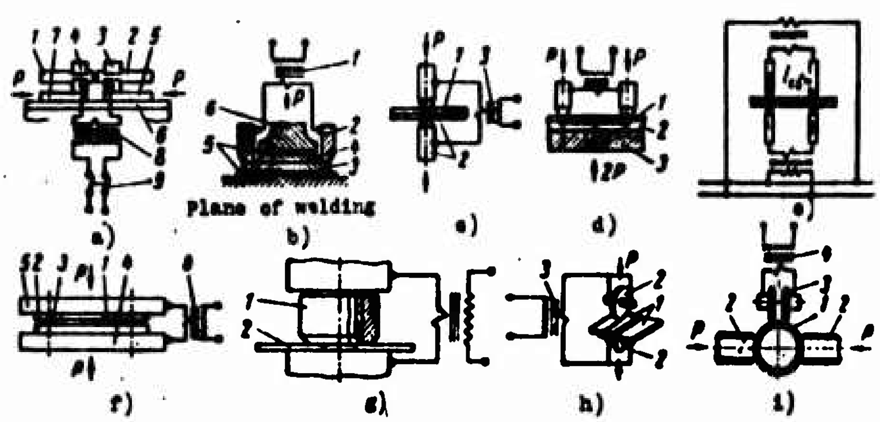


Fig. 37. Diagram of the most important methods of contact welding.

welding transformer is connected to the rectifying installation; due to inductance of the transformer the current in its primary winding grows gradually, as a result of which in the secondary winding is induced gradually a growing impulse of the welding current. Such a form of current pulse technologically is favorable during welding of light alloys.

During welding by stored energy, the energy necessary for execution of separate welding operations relatively slowly is stored in capacitors, in the magnetic field of a special welding transformer, in revolving parts of an electrical generator or in a storage battery. Then it quickly is supplied to the welding circuit in the form of an impulse of great capacity (directly or through a welding transformer). The stored energy (class of capacitors) is widely used for point, roller and joint welding of parts from ferrous and nonferrous alloys of small thickness and section; more rarely for spot welding of parts made of light alloys in thickness greater than 1-1.5 mm and also for joining in T-connection thin-walled tubular elements. The amount of energy expended during every welding operation is the same, which ensures constancy of quantity of separated heat and stable quality of joinings.

The diagram of basic methods of contact weldings are shown in Fig. 37.

Joint welding is produced by resistance or fusion. In both cases welded parts 1 and 2 (Fig. 37a) are pressed in copper electrodes (sponges) 3 and 4 in right and left clamps. The right clamp is fixed on a mobile plate (support) 5 by a travelling force P in directrixes 6, and left – on a motionless plate 7. The welding transformer 8 is united with plates by flexible tires and is fed from a network through switch 9.

Welding by resistance is conducted without melting of metal end-to-end. The parts are brought together until they touch and are pressed together with force P, after which the current is turned on. Parts in the zone of contact are heated and are welded. Quality of welding is increased for protection of joint from oxidation by city gas or throughly dried and purified from oxygen by nitrogen.

During welding by fusion the parts are brought together, with the current on, until formation of electrical contacts, in which occurs fast heating of the metal, accompanied by its melting and partial evaporation around the contact crosspieces and ejection from the zone of welding of the melted pieces of metal. After formation on the butts of the parts of a film of molten metal quickly force P (producing upsetting of joint) is applied. The melted metal is displaced from the gap between the faces and welding is done. Parts with large section (besides sheets) before fusion frequently are heated by current pulses, locking their faces closely (welding by fusion with preheating). The force of upsetting is transmitted to the welded parts by frictional force, developed in clamps, and for short parts partially is received by the unloading clamp supports.

During welding according to the method of Ignat'yev current, carried from the transformer 1 (Fig. 37b) to the electrodes 2, flows in parallel planes of joining of parts 3 and 4, located between asbestos linings 5. After uniform heating to temperature 1200-1280°C the parts are compressed by press 6 and are welded.

Spot welding occurs two- or one-sided. For two sided welding, parts 1 (Fig. 37c) are compressed by force P between electrodes 2 of the spot machine. After switching on transformer 3, the central part of the column of metal, pressed between the electrodes quickly

is heated to melting. Then the current will be turned off and force P is removed. During cooling will be formed a welded point with poured nucleus. During one-sided welding (Fig. 37d) current is distributed between the upper and lower parts 1 and 2. Welding is carried out by a current flowing through the lower part and copper lining 3. For a thickness of steel more than 1.5-2 mm best results are given by bilateral two-spot welding (Fig. 37e), for which two welding transformers are located on both sides of the welded parts.

Relief welding for which simultaneously is welded several points, constitutes a variation of spot welding. Welded parts 1 and 2 (Fig. 37f) are tightly adjoined one to another by flanges (reliefs) 3, preliminarily stamped on one of the details in spots, subject to welding. By force P, the parts are preliminarily compressed between motionless plate 4 and vertically traveling plate 5. By the current brought in from transformer 6, the flanges are heated, and by force P are flattened and are welded.

During T-shape welding, part 1 of small cross-section (boss, pin, stub pipe) is welded to sheet 2 (Fig. 37g). Good results are obtained during localization of heating and welding in places of stamped or mechanically treated flanges.

Roller welding is produced on a machine, for which electrodes usually are revolving disks (Fig. 37h). The welded parts 1 are compressed between electrodes 2 by force P. The current from the welding transformer 3 is brought in to the electrodes, having (one or both) compulsory rotation from a special drive. After compression of details simultaneously with inclusion of current the electrodes start to revolve, carrying the welded article. Roller welding can be continuous (current is on during all the time of welding of seam)

and intermittent (brief current pulses are alternated with pauses of fixed duration). The sequence of welded points will form a continuous tight seam. During step welding inclusion of current and shift of parts occurs by turn. This method especially is expedient for welding of light alloys.

Rollerjoint welding is applied for manufacture of pipes. The blank is bent in the forming part of the pipe-welding machine 1 with joint (Fig. 37i)above and shifts along its own axis. Necessary for welding pressure in butt joining is created by force P, applied to rollers 2. Electrical current is brought to the welded edges by copper electrodes 3 rolled around the pipe united with transformer 4.

The region of application of different methods of contact welding (alternating current) are given in Table 60.

Table 60. Regions of Application of Different Methods of Contact Electric Welding

Method of welding	Region of application
Joint	Lengthening of constructive elements (welding of rails, tubular coils in boiler construction, steel tapes in rolling production, reinforcement of reinforced concrete and others). Joining of details from heterogeneous metals and alloys (welding of tool steel during manufacture of valves of motors and others). Formation of details of closed contour (welding of rims of wheels, flanges, wreaths, and sections of chain). Formation of complicated units from simple blanks (welding of housing of semiaxis of automobile and others)
Resistance	Welding of steel wire, sections of chains of small gauge (to 19 mm); welding of pipes by diameter to 42 mm (with gas protection from oxidation)
Fusion without preheating	Welding of steel sheets, pipes and units from profile metal, stamps and forgings, allowing fast heating and cooling; welding of sections of chains of large guage; welding of details from light alloys; welding of rails

Table 60 (Continued)

Method of welding	Region of application
Fusion with pre-heating	Welding of parts of heavy-gage (thick-walled pipes) alloyed intensely with hardened steel (tool blanks)
By the Ignat'yev method	Welding of tool blanks
Point	Joining of overlapping sheets and profiles of steel and nonferrous metals. Manufacture of stampwelded units and frame constructions with sheet errors. Welding of steel rods transversely during manufacture of grids and frames of reinforcement of reinforced concrete
Continuous* (the most wide-spread process)	Welding of low-carbon and low-alloy, unhardened steels and nonferrous metals
Multipulse*	Welding of steel of thickness more than 6 mm
With heat treatment	Welding of carbon and alloy steels in responsible constructions
Two sided one spot	Most widespread method of welding of forged-welded units of small and average size
One-sided mono-point	Applied in combination with portable devices ("pistols," "levers") and as the element of multi-charpened machines of consecutive action
One-sided two-point	Applied during welding of units of large dimension (railroad car construction) and in multiple-projection machines of consecutive action
Relief and T-shape	Welding of small parts from low-carbon steels in mass production
Roll welding	Welding of barrels, metallic tares, fire extinguishers, etc.
Continuous*	Sometimes applied for welding of thin sheets (to 1 mm) from low-carbon steels, and also during roller-butt welding of pipes (see below) at a rate of 6 m/min
Intermittent*	Most widespread method of roller welding used for welding of details from low-carbon and stainless steel, heat-resisting alloys, aluminum alloys and certain copper alloys
Step	Best method of welding of details from light alloys
Two-sided	Welding of parts of small and average dimensions (the most wide-spread, universal method)
One-sided one seam	Sometimes used for welding of thin steel shells of large dimension
One-sided two seam	Sometimes is applied in mass production
Roller-butt	Production of thin-walled pipes from carbon and low-alloy steels, and also from aluminum and its alloys

*These methods of welding can be carried out in diverse variants (bilateral welding, one-sided etc.).

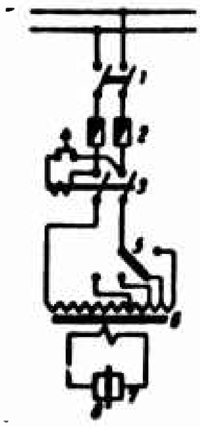


Fig. 38. Electrical diagram of machine for contact welding: 1 — knife switch; 2 — safety fuse; 3 — magnetic contactor; 4 — starting push button; 5 — sectional switch; 6 — welding transformer; 7 — electrodes; 8 — welded parts.

Equipment

General characteristics

and basic elements. The simplest electrical diagram of a contact machine is shown in Fig. 38. In machines of great capacity for point and roller welding instead of a contactor is installed an ignitron (tube) switch, allowing exact adjustment of duration of heating and consumed capacity.

Necessary brief capacity of machine during welding

$$P_{пр} = \frac{I^2 Z}{1000} \text{ kva},$$

where Z is the full resistance of machine and welded details.

Operating conditions of machine is determined by duration of being on

$$ПВ = \frac{t_{св}}{t} 100\%,$$

where t_{CB} is the duration of flow of current during welding and t is the full duration of cycle of welding.

Maximum welding current approximately is equal to

$$I_{2\,\max} = k \frac{P_{\max}}{E_{2\,\max}},$$

where $E_{2.max}$ is the biggest voltage of idling of the welding transformer; k is the coefficient, usually equal to 1.2-1.5. For constant E_2 current I_2 decreases with increase of area of welding contour of machine (for instance, with increase of its useful overhang L, see

Table 61. Characteristics of Certain Serial Machines for Joint Welding

Indices	Types of machines					
	MS-0.75-2	ASP-10	MSR-50*	SM-50-1	MSMU-150	MSGA-300**
Primary voltage in v	200	220 or 380				380
Rated power in kva	0.75	10	50	50	150	300
Nominal duration of being on PV in %	8	8	20	45	20	20
Limits of adjustment of secondary voltage in v	0.48-1.10	1.2-3.2	2.7-5.1	2.6-5.2	4.04-8.10	5.42-10.84
Biggest section of welded details from low-carbon steels during continuous work in mm^2	1.1	50	400	600	1000 — at Automatic operation 2000 — at Semi-automatic operation	5000
Possible number of weldings per hour	540	180	90	180	80	20
Principle of action of machine	Automatic		Nonautomatic	Automatic or semiautomatic		
Maximum effort of upsetting in kg	3	100	3000	3000	6500	25000
Drive of mechanism of upsetting	Spring		Gear	Motor-cam		Hydraulic

*Analogous machines are put out with capacity 75 and 100 kva.

**Analogous machines are put out with capacity 500 kva.

Fig. 40) due to growth of induced drag and with introduction in contour of ferromagnetic metal; P_{HOM} is the rated power indicated in the log book of the machine.

Machines are subdivided into joint, point (including press for relief welding) and roller.

Joint machines (Table 61). Automatic machines of small capacity (from 0.75 to 10 kva) are intended for welding by wire resistance; machine of average capacity with gear (series MSR) or motor-cam drive (SM-50-1) — for welding by fusion with preheating of tool blanks, reinforcement of reinforced concrete, etc. Machine MSM-150 (Fig. 39) basically is intended for welding by continuous fusion under conditions of mass production. This machine, and also the machine of series MSGA with hydrodrive allows welding by fusion with preheating with manual control.

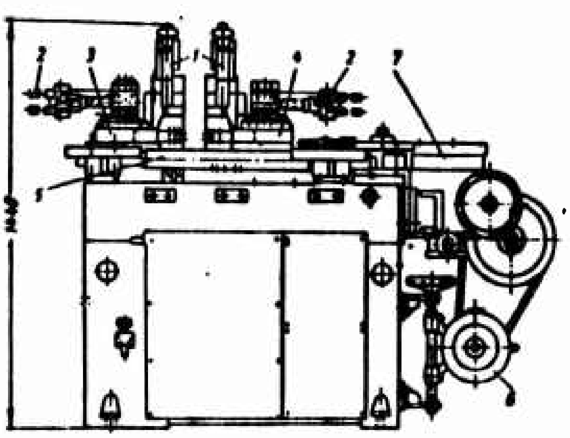


Fig. 39. Automatic joint machine of type MSM-150: 1 — pneumatic clamps; 2 — regulated rests; 3 — motionless plate; 4 — mobile plate; 5 — directrixes; 6 — motor of drive; 7 — box with cam of upsetting.

Machines (construction TsNIITMASh) are also produced for joint welding of thin sheets (δ = = 2-4 mm) width to 450 and 1500 mm, and also a machine for joint welding of strips, pipes, rails, rims of wheels, etc.

Point machines (Table 62). In mass production automatic machines with pneumatic drive of type MTP capacity 75-400 kva (Fig. 40) are widely used. For welding of details of small cross-section and thickness in instrument-making and the electrovacuum industry condensing

Table 62. Characteristics of Certain Serial Machines for Monospot Welding

Indices	Types of machines					
	TKM-7	ATP-10	MTM-50m	MTP-75	MTPT-600	MTPP-75
Voltage of feeding network in v ...	220	220 or 380			380	
Number of phases of feeding network	1	1	1	1	3	1
Method of feeding of welding transformer	Class of capacitors	Alternating current 50 cps			Impulse of direct current	Alternating current 50 cps
Rated power in kva	0.2	10	50	75	600	75
Nominal PV in %	—	20	20	20	8.2	25
Limits of adjustment of secondary voltage in v	—	1.5-2.9	2.7-5.1	3.12-6.24	2.3-6.3	5.62-14.4
Principle of action	Automatic	Nonautomatic	Automatic			
Installation	Stationary					Suspension
Drive of mechanism of compression .	Pedal		Motor-cam		Pneumatic	
Maximum force, developed on electrodes, in kg	56	250	200	540	2600 (for peening 6500)	200-330
Maximum thickness of welded part (C — from steel; A — from light alloys)	0.02 + 0.02 0.7 + 0.7	2 + 2 — C	2 + 2 — C	2 + 2 — C	4.5 + 4.5 — A	1.5 + 1.5 — C
Maximum number of weldings per hour	1000	600	3000	4200	1200	3600

Note: Machines of type ATP are released also with a power of 25 kva; type MTP — capacity 100; 150; 200; 300 and 400 kva; type MTPT — capacity 400 and 1000 kva.

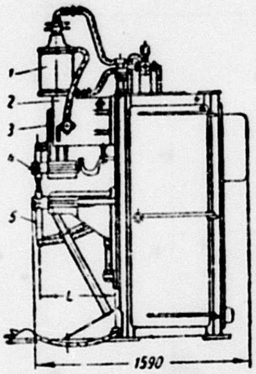


Fig. 40. Point machine MTP-75: 1 — pneumatic cylinder; 2 — upper bracket with directing; 3 — mobile head; 4 — upper arm of machine; 5 — electrodeholder (candle); L — useful overhang of machine.

machines (TKM and others) widely are used. Specially for welding of details from light alloys are intended machines of series MTPT. Suspension machines of type MTPP-75 with pneumatic drive for welding of steel parts in thickness to 1.5 + 1.5 mm and armature rods transversely have been produced.

In production of automobiles, railroad cars, diesel locomotives and electric locomotives, agricultural machines and others, besides universal monopoint machines, widely are applied two- and multiple-projection machines for mono- and bilateral welding (see Fig. 37d and e). In automobile construction are used also different portable devices (pistols, welding jacks and others). In the last case bulky articles from thin stamped sheets and profiles gather in a conductor which is part of the welding installation.

Special multiple-projection automatic machines are released for welding of reinforcement grids and frames.

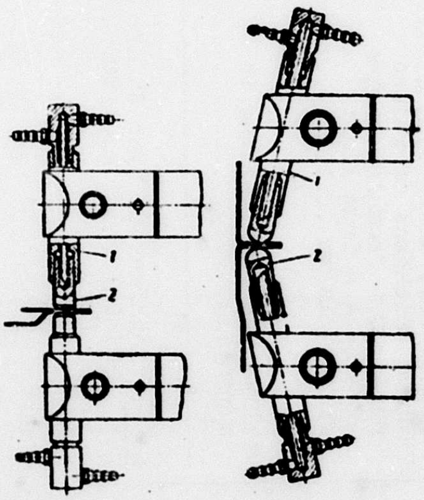


Fig. 41. Operating tool of point machines.

Depending upon form of welded parts the tool of point machines is changed (Fig. 41): electrodeholders 1 and electrodes 2.

Welding presses. Relief and T-shape welding is done on point machines or welding presses of capacity 200-600 kva (MRP-200-600). Presses differ from point machines by smaller useful overhang, increased force of compression (on press

Table 63. Characteristic of Certain Serial Machines for Roller Welding

Indices	Types of machines				
	MShK-3-2	Sh-50-1	MShP-100	MShPB-150	MShShI-400
Voltage of feeding circuit in v	220	220 or 380		380	380
Number of phases of feeding circuit	1	1	1	1	3
Method of feeding of welding transformer	Class of capacitors	Alternating current 50 cps			Impulses of direct current
Rated power in kva	3	50	100	150	400
Rated PV in %	—	40	50	50	10
Limits of adjustment of secondary voltage in	—	2.1-4.0	3.3-6.6	3.8-7.7	3.0-8.4
Type of interrupter	—	Ignitron			Station of control SPUSh-400
Drive of mechanism of compression	Spring-pneumatic	Motor-cam		Pneumatic	
Maximum force, developed on electrodes, in kg	70	400	800	800	800
Maximum thickness of welded parts (C — from low-carbon steels; A — from light alloys) in mm	0.2 + 0.2 — C	1.5 + 1.5 — C	1.5 + 1.5 — C	2 + 2 — C (with covering)	2.5 + 2.5 — A
Maximum speed of welding in m/min	0.9	3.75	1.9	1.9	0.5

Note: Machines of type Sh are made also with capacity 25 kva; type MShP — 150 and 200 kva; type MShShI — 600 and 1000 kva.

MRP-600 to 5500 kg) and presence of flat contact plates.

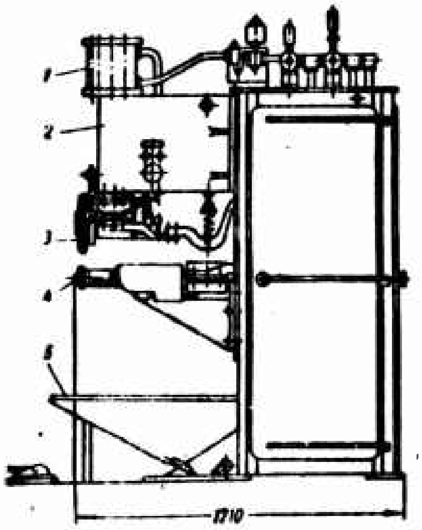


Fig. 42. Roller machine MShP-100-1: 1 — pneumatic cylinder; 2 — bracket with directing; 3 — upper nonconducting electrode; 4 — Lower drive electrode; 5 — Pan for collection of water during external cooling of electrodes.

Roller machines (Table 63). Responsible parts of steel are welded on machines of series MShP with ignitron interrupters (Fig. 42), released for welding of transverse or longitudinal seams (electrodes turn 90° around a vertical axis). For welding of very thin parts condensing machines (for instance, MShK-3-2) are used. For welding of steel with coverings (zinc, lead) the machine MShPB-150 is made in which copper disk electrodes revolve around steel cutters with rolling, ensuring continuous stripping of operating surface of electrodes of remaining particles of metal — covering.

Roller welding of light alloys successfully is produced on machines MShShI-400 and analogous machines of high power with step supply and feeding of transformer by impulses of direct current.

For roller-joint welding of longitudinal seams of pipes in diameter to 156 mm with thickness of wall to 6 mm we use a machine by capacity to 750 kva. Speed of welding on these machines at frequency of current to 150 cps is 20-50 m/min.

Technology of Welding

Joint welding. Mainly welding by fusion is used (perlitic and austenitic steel, heat-resisting and aluminum alloys).

Technological conditions of good welding by fusion: heating

to appearance on faces of parts of film of molten metal and full removal of this metal from joint during upsetting. Process of welding by fusion is determined by following parameters:

a) adjusting length l (issue of details from electrodes), affecting heating. During welding of steel details in diameter d $l =$ $= (0.7$ to $1.0)$ d;

b) allowance for fusion and speed of fusion, determining degree of heating of parts (during welding without preliminary preheating); usually fusion is produced on 6-20 mm with average speed 1-8 mm/sec; during welding with preheating (to 800-1000°C) allowance is 30-50% less; in the presence in steel of a large quantity of chromium (stainless steel) or silicon (transformer steel) the speed of fusion is increased for prevention of oxidation of metal in the zone of welding;

c) specific power q kva/mm^2, increasing with increase of speed of fusion and with decrease of duration of welding; during welding by continuous fusion of steel parts in mass production q = 0.15 to 0.40 kva/mm^2; during welding with preheating under the same conditions q = 0.12 to 0.16 kva/mm^2; during welding with preheating in small-lot production q = 0.05 to 0.8 kva/mm^2; during welding of rings q is increased by 40-60%;

d) total shortening Δ_{oc} of welded parts during upsetting, its speed v_{oc} and specific pressure p kg/mm^2: usually Δ_{oc} = 3 to 8 mm; v_{oc} = 20 to 60 mm/sec (high speed during welding of alloy steels); during welding by continuous fusion of low-carbon steels p_o = 5 to 7 kg/mm^2; during welding of alloy steels of perlitic class p_{oc} = = 7 to 14 kg/mm^2; during welding of austenitic steels p_{oc} = 20 to 25 kg/mm^2; during welding with preheating p_{oc} drops by 25-40% in connection with ease of plastic flow;

e) duration of process t_{CB}, depending on section and material of welded parts and on capacity of applied equipment (usually t_{CB} = = 3 to 40 sec; for parts with section 5000-20,000 mm^2 t_{CB} attains 3-8 min).

Spot welding. In the section of a welded point is a lentil-like nucleus with columnar structure of poured metal, surrounded by a zone of overheating with big grain, after which follows (during welding of steel of perlitic class) a zone of small normalized grain, transient in basic metal.

The diameter of nucleus d_T, determining durability of point, depends on heating of parts during welding, i.e., on the technological process. During normal process and $\delta \geq 0.5$ mm the diameter of nucleus $d_T = 2\delta + 3$ mm (δ is the thickness in mm of the thinner of the welded details), and $d_э = d_T$, where $d_э$ is the diameter of the contact surface of the electrode.

Low-carbon (Table 64) and austenitic stainless steel are spot welded better than others. For increase of plasticity of points during welding of hardened steels electrothermal treatment of them directly on a point machine is expedient.

Of the copper alloys the best welded is siliceous bronze. Brass Л62 is welded satisfactorily, copper — badly. Spot welding of aluminum and magnesium alloys is widely done.

Before spot welding steel is cleaned of rust and cinder; aluminum alloys, of film of Al_2O_3 (by etching or mechanically).

Relief welding. Normal diameter of each protrusion is 3-5 mm; its height, 0.75-1.5 mm. Necessary capacity of the welding machine is 25-75 kva for each welded flange. Necessary force of compression of each protrusion depends on thickness of the stamped part. For

Table 64. Tentative Conditions of Spot Welding of Low-Carbon Steels on Automatic Machines

Thickness of detail in mm	Diameter of contact surface of electrode in mm	Effort, applied to electrodes, in kg*	Duration of inclusion of welding current in sec**	Tentative current in a	Approximate capacity of machine in kva
0.5	4	50-100	0.1 - 0.2	4000-5000	10-20
1.0	5	100-200	0.2 - 0.4	6000-8000	20-50
1.5	6	150-350	0.25-0.5	8000-12000	40-60
2.0	8	250-500	0.35-0.6	9000-14000	50-75
3.0	10	500-800	0.6 - 1.0	14000-18000	75-100
4.0	11	600-900	0.8 - 1.2	15000-20000	100-150
5.0	13	800-1000	0.9 - 1.5	17000-24000	150-200
6.0	15	1000-1400	1.2 - 2.0	20000-26000	200-250

*During welding of low-alloy steels the force is increased by 40-50%.

**Duration of full cycle of welding of one point depends on type of welding machine.

δ = 1 mm, P = 150-180 kg; for δ = 3 mm, P = 500-600 kg. High quality of welding is ensured only during exact stamping of details and flanges.

Roller welding. Stable quality of seam without damage of external surface of the welded part and without excessive wear of electrodes is ensured by intermittent flow of welding current or with step welding.

The ratio $t_{CB}/(t_{CB} + t_{\Pi})$ usually lies within the limits 0.5-0.7 for steel and 0.25-0.50 for aluminum alloys (t_{CB} is the duration of one impulse of turning on of the welding current; t_{Π} is the duration of pause between sequential impulses).

Tentative conditions of roller welding of low-carbon steels are given in Table 65. By this method austenitic steel, heat-resisting and light alloys are successfully welded.

Table 65. Tentative Conditions of Roller Welding to a Durably-Tight Seam of Parts Made of Low-Carbon Steels

Thickness of detail in mm	Width of operating surface of electrode in mm	Force, applied to electrodes, in kg	Duration in sec		Tentative welding current in a	Speed of welding in m/min
			Current pulse	Pauses		
0.5	4	100-200	0.04-0.06	0.02-0.06	6000-10000	1.0-2.0
0.8	5	150-300	0.06-0.08	0.04-0.08	8000-13000	1.0-1.5
1.0	6	200-400	0.06-0.08	0.04-0.10	10000-14000	1.0-1.5
1.2	7	250-450	0.08-0.12	0.06-0.12	12000-16000	0.8-1.0
1.5	8	300-550	0.10-0.14	0.08-0.16	14000-18000	0.6-0.8
2.0	10	400-700	0.12-0.16	0.10-0.20	16000-20000	0.5-0.6

Electrode materials. Materials for electrodes of contact machines have to have: a) high electro and thermal conduction; b) high hardness; c) high temperature of recrystallization and d) small inclination to formation of alloys with metal of welded parts. Copper pure or with additions of chromium (Br.Kh 0.7) or cadmium (to 1%), and also complicated alloys (MTs-5B) find application here.

Durability of Joints

Joints, welded by butt-to-butt fusion, possess high durability during static and cyclical loads, and also prolonged durability at high temperatures close to prolonged durability of basic metal.

Welding butt-to-butt by resistance (without special gas protection from oxidation) is not recommended for responsible joinings. Minimum values of static durability per cut of well welded points are given in Table 66.

Durability of welded points during work on breaking away is for unhardened steel 60-75% and for aluminum alloys 30-40% of the minimum durability of points during cutting.

Table 66. Minimum Values of Durability of Welded Point (in kg) During Static Load on a Cut

Thickness of welded details in mm	Diameter of nucleus of welded point in mm	Destructive load for one point during test on a cut in kg				
		Low-carbon steel of brands 10 and 20	Low-alloy steel (30KhGSA, 40KhNMA)	Stainless and heat-resisting steel and alloys (1Kh18N9T, Kh25N13, KhN78T)	Aluminum alloys	
					D16T V95T	AMg
0.5	3.0	180	220	240	70	50
1.0	4.0	450	600	650	160	140
1.5	6.0	1000	1200	1200	300	250
2.0	7.0	1400	1800	1800	420	380
3.0	9.0	2000	2600	2600	700	600
4.0	12.0	3200	4000	4000	1200	850

Coefficients of durability during static load of durably tight connections, carried out by roller welding, are given in Table 67. For mechanically and thermally unreinforced materials they are close to one.

The fatigue limit of elements of constructions with joints overlapping, done by point and roller welding, can essentially be lowered as a result of local change of structure of material in the zone of welding and appearance in it of unfavorable residual stresses, and also due to significant concentrations of stresses.

The coefficient of durability during pulsating cycle loading (on extension) and binding joints lies within the limits 0.5-0.8 (smaller value corresponds to mechanically or thermally reinforced materials). The coefficient of durability of operating overlap joint (point and roller) during pulsating cycle of extension of flat samples can be lowered to 0.08-0.15. For roller joints it is 50-100% higher than for point. Fatigue limit of roller joining butt-to-butt

Table 67. Coefficient of Durability During Static Load Per Cut of Durably-Tight Connections, Carried out by Roller Welding on Parts of Thickness 0.5-2.5 mm

Material	State before welding	Coefficient of durability
Low-carbon steel	Annealed	0.9-1.0
	Cold-rolled	0.8-0.9
Steel 30KhGSA, 40KhNMA.......	Normalized	0.8-0.9
Steel 1Kh18N9...	Clamped	0.95-1.0
	Cold-rolled	0.7-0.8
Nichrome KhN78T.	—	0.8-0.9
Duralumin D16T..	Thermally hardened	0.5-0.6
Aluminum alloy.. V95T.........	Thermally hardened	0.3-0.4

with cover plates is 2-3 times higher than joining by overlapping. The fatigue limit of nonplanar overlap joinings is significantly higher than for flat ones (from smaller stresses of bend).

Gaspressing Welding

During gaspress welding the welded parts of metal are heated simultaneously over the entire area of section by multiflame burners, and after heating to required temperature they are compressed — upset.

Two methods of welding are distinuished: in the plastic state and with fusion of combinable faces.

Gaspressing welding is used for butt joining of rods, pipes, profiles, rods, strips. It is executed on special machines (Table 68), equipped for heating by acetylene-oxygen injection burners (Table 69).

For welding of pipes under field conditions are used mobile welding installations, consisting of several units: tractor-stacker, welding head, mobile acetylene gas producer, oxygen bottles. Characteristics of welding heads are given in Table 70.

Table 68. Technical Characteristic of Machines for Gaspress Welding

Characteristic	Type of machines							
	SGP-3	SGP-3r	SGP-4	SGP-1	SGP-1r	SGP-2	SGP-7	MGPS-15/160
Drive:								
pressing	Manual		Manual	Manual		Pneumatic		
compressions and upsetting	Manual		Manual	Pneumatic		Pneumatic		
Oscillatory control by burner	Manual		Manual and from electric motor	Manual		Pneumatic	Pneumatic and manual	Pneumatic and manual
Biggest force in kg:								
pressing	6000	4000	22000	20000	22000	30000	25000	30000
compressions and upsetting	4000	2000	15000	14000	14000	15000	13000	15000
Biggest area of welded cross-section in mm^2	1000	1200	4500	4500	6000	4500	8000	6000
Biggest diameter in mm:								
pipes	60	60	110	80	160	80	160	160
rods	35	40	75	75	85	75	100	—
Dimensions in mm:								
length	800	850	1680	1540	—	2000	1630	2025
width	400	420	760	600	—	1270	1150	975
height	650	585	1350	1350	—	1635	1330	1275
Weight of machine in kg	150	219	850	800	950	2000	2000	1300-1470

Table 69. Technical Characteristics of Acetyleneoxygen Burners for Gaspress Welding

Type of burner	Welded parts	Number of barrels	Construction of burner	Expenditure of acetylene in 1/hr	Arrangement of nozzles in head of burner	Weight of of burner in kg
MG-R	Rectangular cross-section size up to 13.76 mm	1	Head with two tips tightly connected to the barrel	1900	Single-row	2.1
MG-52	Round solid section by diameter to 52 mm	2	Two burners, united hinged	3500	The same	4.8
MG-75	Round section in diameter to 75 mm	2	The same	4500	Double-row	4.9
MG-40	Pipes 1-1 1/4" ..... Rods in diameter to 35 mm	1	Burner in two parts, united by hose	1500	Single-row	2.7
MG-55	Pipes 2"	1	The same	1800	The same	
MG-80	Pipes 3"	1	The same	2400	The same	
MG-50T	Pipe with external diameter to 50 mm	1	Head in two parts, united by a cock device with one barrel	2000	The same	4.5
MG-100T	Pipe with external diameter to 100 mm	1	The same	2600	The same	5.6
MG-150T	Pipe with external diameter to 150 mm	1	The same	4200	The same	6.4
MG-60	Round section by diameter to 62 mm	1	The same	3500	The same	—

Table 70. Technical Characteristic of Heads for Welding of Pipes

Type	External diameter and thickness of machines of welded pipes in mm	Number of cylinders		Diameter of cylinders		Maximum developed force in kg during pressure of 5 atg		Weight of head in kg
		Vertical	Horizontal	Vertical	Horizontal	Radial pressing of pipes	Longitudinal compression	
219/273	219 × 8 273 × 10	2	4	190	140	64700	30750	1322
325/377	325 × 12 377 × 12	2	4	230	165	99000	41130	1530
529/630	529 × 12 630 × 12	2	4	305	210	163000	69250	2520

Gaspressing welding is a highly productive process, among the advantages of which by comparison with contact joint electric welding are: independence from sources of supply of electric power; high power of acetyleneoxygen installations with small weight; simplicity of technological process and servicing; simple clamp arrangement, not requiring feed of current and purification of surface of parts.

NEW METHODS OF WELDING

Welding by Electron Beam in Vacuum

Essence of process and fields of its application. During bombardment of a metal surface by fast-moving electrons in high vacuum, their kinetic energy is practically without losses converted into thermal energy. Temperature at place of bombardment attains 5000-6000°C.

Electrons are emitted by the cathode of the electron gun and under action of high electrical potential between cathode and anode are accelerated to high speeds which, depending upon magnitude of accelerating voltage, can attain 115,000-165,000 km/sec.

Thermal power which separates on surface of processed material is proportional to number of electrons which collide with it per unit of time, and to their kinetic energy. For an increase of specific power in spot of heating and a decrease of width of zone of melting, the electronic beam is focused by electrostatic lenses or a magnetic field. In the contemporary units for welding, drilling, cutting or milling, the electron beam is focused on an area with a diameter of up to 0.001 cm, which corresponds to a specific power in spot of heating of $5 \cdot 10^5$ kilowatts/cm^2 [46] for a beam power of 100 w.

During shift of component under the motionless or mobile beam, a welded seam forms. Sometimes, welding is produced by means of a

shift of the beam itself along motionless edges, with the help of deflecting systems. Finally, the beam can be directed along welded edge by a mechanical shift of the electron gun. Deflecting systems are used also for oscillations of the electron beam across or along the seam, which allows to weld with additive metal and to increase or to decrease width of welded seam. For limitation of heating of material in zones adjacent to place of welding, and for limitation of evaporation during welding of volatile metals, feed of current is by short, powerful impulses. Applied pulse generators give frequencies from 1 to 3000 cps with a pulse length from 0.01 to 0.00005 sec. Prolonged pulses and large ratios of pulse duration to duration of cycle (pulse plus interruption) are applied during electron beam welding. Sometimes pulses are repeated with a small frequency to obtain separate welded spots instead of a continuous seam.

One of the advantages of welding by electron beam in vacuum is absence of contaminations which usually get into seam from electrode and from protective atmosphere. Working vacuum of $1 \cdot 10^{-4}$ mm of mercury column corresponds to cleanliness of medium, in which welding is produced 0.1-0.01 parts per million, which is unattainable during welding in argon or helium [33].

As distinct from usual welding sources of heat, heating by electron beam is carried out not at the expense of thermal conduction, and the heat separates directly in the actual metal; besides, it is most intense at a certain depth under its surface. Depth of penetration of electrons in metal depends on accelerating voltage and properties of metal.

At present use is made of units with low (from 10 to 30 kv) and high (upto 200 kv) accelerating voltage. A distinctive peculiarity

of units of the second type is possibility of obtaining deep-melting and a narrow seam with a comparatively small power of beam. Ratio of depth of melting to width of seam can attain 15-20. However, during use of high accelerating voltage, additional protection from hard X-radiation is necessary.

Deep melting may be obtained also during low accelerating voltage by means of an increase of beam power and an increase of density of energy in it. During work with low accelerating voltage, hardness of X-radiation is significantly less and X-rays are absorbed by walls of vacuum chamber.

During welding by electron beam with high specific power, there is observed an intense evaporation of metal in spot on surface of article. As a result, there will form a hole of conical form. Specific power on lateral surface of hole decreases, compared to specific power in base of cone, and intensity of evaporation of metal is lowered. Resulting cone of melting is very stable, since during its filling with liquid metal, there is increase in energy absorbed by the surface, which leads to intense evaporation of metal and restoration of initial form of hole [26].

In its own specific power, mobility and precision, the electron beam differs advantageously from till now known sources of heat. This allows to use it for welding of refractory and chemically active metals (molybdenum, tungsten, niobium, zirconium, titanium and others), alloys with volatile components (zirconium with tin, steel with admixture of aluminum), for soldering of metals to nonmetallic materials, for drilling of holes in jewels serving as bearings of precision instruments, for obtaining micro-cuts in resistors, for drilling ferrite materials and semiconductors. Deep penetration of beam in

metal allows to execute tee joints and to produce welding in difficultly accessible places of construction. Especially large prospects are in view for this method in atomic power engineering, airplane and rocket construction, radioelectronic industry, precision machine building and instrument building.

Equipment for electron welding. Schematic diagram of unit for electron-beam welding is shown in Fig. 43. Above vacuum chamber 1 is located electron gun 2 with devices, focusing and deflecting systems. Inside chamber is placed attachment 3 for bracing and shifting of welded components 4. On the outside is located drive 5. Electrical equipment consists of filament transformer 6, high-voltage transformer with rectifier 7, modulator 8, control panel 9 with feed block focusing 10 and deflecting 11 systems. Vacuum system consists of fore pump 12, high-vacuum steam-oil unit 13 and valves with slides.

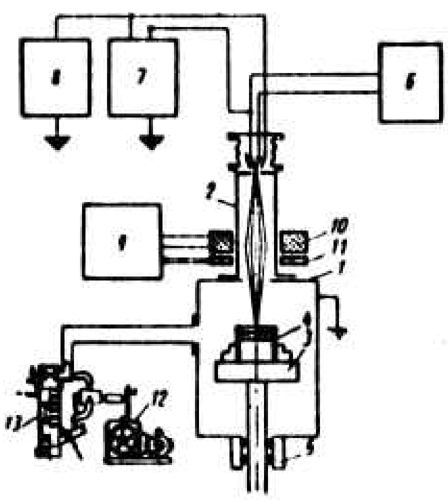


Fig. 43. Schematic diagram of unit for electron beam welding.

Cathode of electron gun is a tungsten, flat spiral from wire of 0.25-0.3 mm diameter. However, such cathodes are short-lived and possess comparatively low emission properties. More expedient are cathodes with indirect heating, constituting a cap, on face surface of which is applied an active layer of lanthanum boride. Cathodes from lanthanum boride work stably at a temperature of 1650°C. Their service life is about 250-300 hours.

Low-voltage electron guns simpler in construction consist of cathode 1, focusing electrode 2 and anode 3 (Fig. 44). Sometimes,

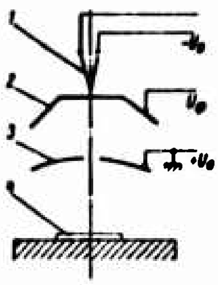


Fig. 44. Diagram of low-voltage electron gun: 1 – cathode; 2 – focusing electrode; 3 – anode; 4 – weldable component; U_0 – accelerating voltage; U_Φ – focussing voltage [5].

for improvement of focusing, one installs in guns focusing electrostatic or magnetic lenses. Welded component is not a link electrical circuit. Because number of lenses is small, low-voltage guns give comparatively large currents of beam that ensures high power. Deficiency of such electronic optics is defocussing effect of space charge of electron beam on section between anode and component. For removal of this defect low-voltage guns are designed in such a way that the anode is the very welded component. Circuit of high-voltage electron gun is shown in Fig. 45. Emission device 1 consists of tungsten cathode, in annular electrode (Wehnelt cylinder), which serves for forming of beam, adjustment of current and modulation of beam by feed of pulse control voltage. Under cathode is located disk anode with a central hole.

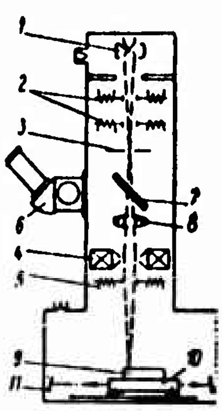


Fig. 45. Diagrams of high-voltage electron gun [37].

High tension between cathode and anode accelerates electrons in beam, but magnetic field of coils 2 ensures stability of beam with respect to axis of gun. With help of diaphragm 3, central part of flow of beam separates, but magnetic lense 4 focuses beam on surface of component. Deflecting coils 5 serve to shift beam on surface of component. Optical attachment, including microscope 6, mirror 7 and objective 8 with axial holes, allows to watch process of treatment with a magnification of 50.

Control circuit of electron beam is shown on Fig. 46. All parts of circuits included in dotted rectangle, are under high potential

and through insulating transformers are included in network of alternating current, but anode is grounded. Pulse generator consists of transducer of cycle and device for pulse shaping. During pause, on Wehnelt cylinder, a high negative voltage is fed and beam is interrupted. During pulse, this voltage is lowered. Decrease of voltage corresponds to difference between regulated voltage fed to Wehnelt and amplitude of pulse. Because of this, it is possible by any means to change current of pulse beam.

In high-voltage guns, current of beam is small, since from the beam there separates out only its central part. Therefore, for compensation of power, accelerating voltage is increased to 150-200 kv.

Focusing lens consists of a coil in a massive iron screen, through central hole of which passes an electron beam.

Deflecting system is in the form of two or four coils connected in series by pair, and fixed at an angle of 180° to one another.

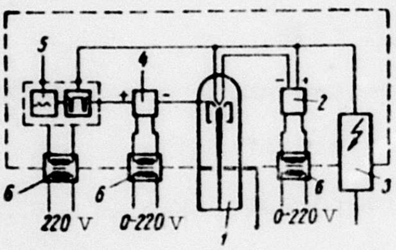


Fig. 46. Control circuit of electron beam: 1 — upper part of electron gun with emission device; 2 — source of direct current for heating of cathode; 3 — high-voltage rectifier; 4 — high-voltage source of direct current; 5 — pulse generator; 6 — insulating transformers [37].

First units for electron beam welding were distinguished by small dimensions of vacuum chambers and were intended for welding of experimental specimens.

Welding chamber of one of first laboratory units ELV-1 (MVTU-MEI [Moscow Higher Technical School-Moscow Electrotechnical Institute]) is designed in the form of a reservoir of 600 mm diameter and about 1 m length and is equipped with inspection windows. Motors of drive of working table are placed inside chamber [27].

Welding is conducted in vacuum not lower than $5 \cdot 10^{-4}$ mm of mercury column.

Laboratory unit of type IES-L1 [25] by the Institute of Electric Welding imeni Ye. O. Paton also has a small cylindrical chamber. Electron beam is focused by an electrostatic system. Diameter of active spot in plane of focusing is regulated by diaphragm-rings fixed on outlet of beam from cathode cap.

Laboratory-type unit of Institute of Metallurgy imeni A. A. Baykov [17] is intended for welding of longitudinal and annular seams on samples and articles having a length up to 200 mm and a diameter up to 150 mm. It has a chamber of 500 × 250 × 300 mm. All mechanisms of drive are located outside chamber.

Technical specifications of these installations are given in Table 71.

Table 71. Technical Specifications of Laboratory Units for Welding with Electron Beam

Characteristic	Type of unit		
	ELV-1 (MVTU-MEI)	IES-L1	IMET
Accelerating voltage, in kv	To 50	10-15	To 20
Current of beam in ma	To 3a	To 150	To 100
Minimum diameter of spot of heating, in mm	1	1	0.6-0.8
System of interruption of beam	Interrupter on side of primary winding of high-voltage transformer	–	–
Source of feed	Transformer of X-ray unit of type RUP; rectifier, assembled on kenotrons	Transformer of X-ray unit GKT-250, kenotron rectifier KRM-150 with filter	Rectifier of X-ray unit VS 50/50

Table 71 (Continued)

Characteristic	Type of unit		
	ELV-1 (MVTU-MEI)	IES-L1	IMET
Vacuum system	Fore pump VN-1, steam-jet pump N-5S	Fore pump VN-461, high-vacuum steam-oil pump TsVL-100	Fore pump VN-1, high-vacuum unit VA-05-1

At present, the Soviet Union and foreign countries are producing industrial units for electron-beam welding. Industrial automatic unit ELU-1 [19], constructed by NIAT, intended for electron-beam welding of longitudinal and annular seams, is equipped with an electron gun with two-cascade focusing – electrostatic and electromagnetic [18]. During adjustment of gun, it is possible to move it in vertical direction 45 mm and to incline 3°, which corresponds to a displacement of beam on horizontal plane by 15 mm. Control of unit is with the help of two panels, on one of which are placed control instruments for shifts inside chamber and for actuating the gun, and on second – control instruments for vacuum pumps and source of feed.

Mechanisms for bracing and shifting weldable articles are fixed on special carts and are rolled along guides during loading and unloading. For welding of cylindrical articles, there is a ten-position attachment of the revolver type with a drum, in clamps of which are braced the components. Drives of actuating mechanisms are located outside chamber.

Industrial automatic unit ELU-2 [19] serves for welding of face seams on cylindrical articles (up to 30 units) without disturbance of vacuum. Electron gun, source of feed and vacuum equipment are the same as for units ELU-1.

Specialized experimental unit R971 for welding of articles of

large dimension, constructed by the Institute of Electric Welding imeni Ye. O. Paton [10], is provided with a cylindrical chamber 3200 mm in length and 1020 mm in diameter (Fig. 47).

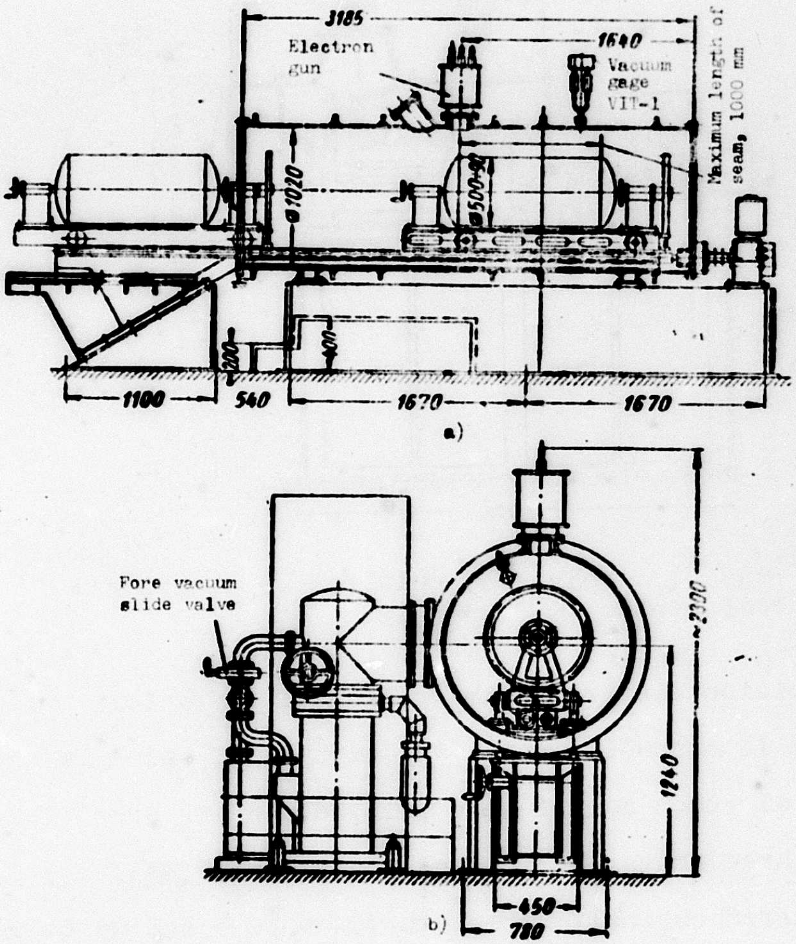


Fig. 47. Cross section of vacuum chamber of experimental unit R971 of Institute of Electric Welding imeni Ye. O. Paton: a) Longitudinal; b) transverse.

Universal unit constructed by the same institute (Fig. 48) is a 12-position, automatic machine for welding of small-size articles [11]. In cylindrical chamber of 1060 mm in length and 500 mm in diameter, it is possible to weld longitudinal and annular seams in

horizontal and vertical planes. Focusing distance of gun changes from 30 to 80 mm.

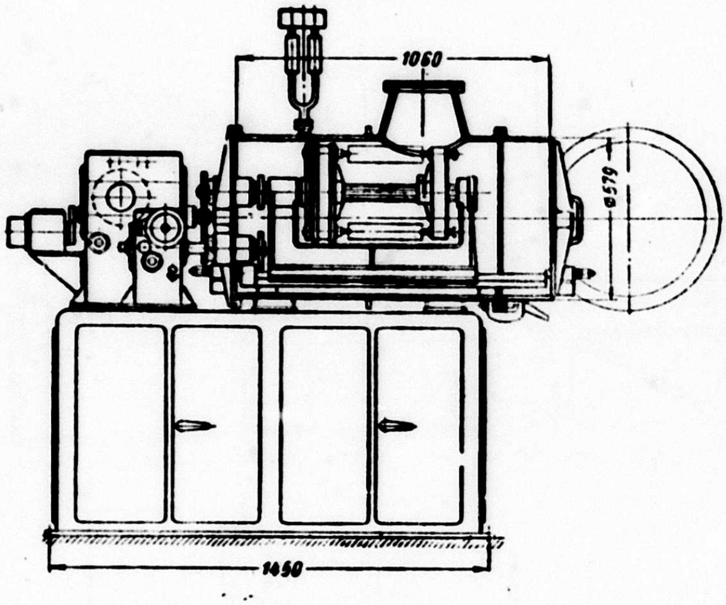


Fig. 48. Universal unit for welding small components.

For precision electron-beam welding of refractory metals and alloys, there is a special unit [9], circuit of which is shown in Fig. 49. In electron gun of this unit, depending upon capacity, cathodes of three types are applied: diameter 3; 4.2 and 5.4 mm for capacities correspondingly more than 3, up to 6 and up to 10 kilowatts for currents of 15-170, 40-300 and 50-500 ma. Accelerating voltage is regulated within limits of 5-20 kv. For these three types of cathodes, beam is focused in spots of diameter of 0.5-1; 0.8-1.5 and 1-3 mm. Working chamber of unit has form of cube with dimensions of 500 × 500 × 500 mm, with hole for loading components to be welded and an inspection window. On lateral faces of chambers are located holes for connection of mechanisms necessary for welding of circular, annular or longitudinal seams.

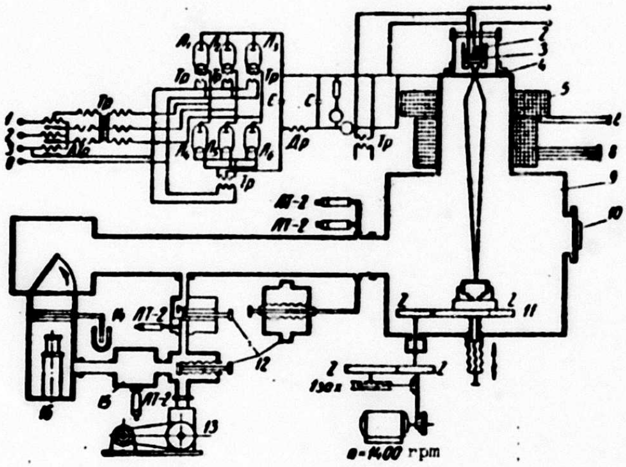


Fig. 49. Circuit of unit for precision electron-beam welding: 1 — to block for feeding of modulator; 2 — modulator; 3 — cathode; 4 — anode; 5 — focusing coil; 6 — to block for feeding of focusing coil; 7 — deflecting system; 8 — to block for feeding of deflecting system; 9 — vacuum chamber; 10 — loading window; 11 — spindle; 12 — vacuum cocks; 13 — fore pump VN-2; 14 — trap; 15 — fore pump; 16 — vacuum unit VA-05-1.

Outside the USSR, units for electron-beam welding are made by the firms Hamilton and Airco (USA), Zeiss (West Germany), Sciaky (France) and others.

Technical specifications of certain industrial units for electron beam welding are given in Table 72.

<u>Technology of welding and property of welded joints</u>. Good quality of welded seams in electron-beam welding may be ensured only by thorough preparation and trimming of weldable edges. Methods and technology of preparation of components in electron beam welding are the same as for argon-arc welding; however, in welding of minute thicknesses (<0.25 mm) more exact assembly and full absence of gap between edges are required. The types of welded joints recommended for electron beam welding are shown in Fig. 50.

During welding of components of large thicknesses, when melting is incomplete, special treatment of edges (Fig. 50a) is applied or welding wire is packed in groove (Fig. 50b). During welding of components of different thickness, special treatment of edges is also accomplished.

Table 72. Technical Specifications of Certain Domestic and Foreign Units of Industrial Type for Electron-Beam Welding

Characteristic	Type of unit and maker						
	ELU-1*	R971 IES**	IES**	A.306.02	Hamilton (USA)	Sciaky (France)	Airco (USA)
Use..........	For welding of longitudinal and annular seams, automatic	For welding of articles of large dimension	For welding of small-size articles, automatic twelve-position	For precision electron-beam welding of small-size components	For precision welding and treatment of materials	For welding longitudinal, annular and circular seams	For welding longitudinal, annular and circular seams
Dimension of weldable articles, in mm...	250 × 1000 (flat)	Length up to 1200, diameter up to 70	Length up to 250, diameter up to 60	—	—	—	—
Focusing system of electron beam.....	Two-cascade: electrostatic and electromagnetic						Two-cascade: electrostatic and two focusing electromagnetic coils
Minimum diameter of spot of heating, in mm............	0.8-1.5	1	1	0.5	0.01		1
Speed of welding in m/hr...	5-50	10-100	20-80	To 80	To 45	To 150	
Source of feed	Transformer OMS-5/10, selenium rectifier (25 kv, 3 kw), assembled in accordance with Larionov circuit, without filters	Three-phase, high-voltage transformer, 50 kva, 22 kv, high-voltage rectifier on kenotrons VA-0.1/40, assembled in accordance with Larionov circuit, 3 lamps in arm	Standard block for feeding X-ray unit VS 50/50 (50 kv, 50 ma)	Three-phase, high-voltage transformer with rectifier (20 kv, 200 ma or 20 kv, 1a)	Single-phase high-voltage transformer with rectifier	High-voltage transformer with retifier	Three-phase high-voltage transformer with rectifier

*For welding of face seams on cylindrical articles, use is made of unit ELU-2 of the same characteristics as ELU-1.

**Constructed in Institute of Electric Welding imeni Ye. O. Paton.

Table 72 (Continued)

Characteristic	Type of unit and maker						
	ELU-1*	R971 IES**	IES**	A.306.02	Hamilton (USA)	Sciaky (France)	Airco (USA)
System of interruption of beam..........	—	—	Self-interrupter 300 pulses/sec	Modulation of voltage fed to focusing electrode. Pulse duration 0.005-0.5 sec	Pulse generator. Pulse duration from 0.01 to 0.0005 sec	—	—
Vacuum system.	2 fore pump VN-1, high-vacuum unit VA-5-4 with steam-jet pump N-5T	Fore pump VN-1, high-vacuum unit VA-5-4 with steam-jet pump N-5T	—	Fore pump VN-1, high-vacuum unit VA-2-3	Fore pump with high-vacuum unit		System of four vacuum with high-vacuum unit for separate pumping from chamber and gun
Accelerating voltage, in kv............	To 25	To 20	To 50	To 20	25-150	To 30	To 15
Current of beam, in ma...	To 50-70	To 500	To 50	15-500	To 20	To 100	To 500
Power of beam, in kv.........	To 1.5	10	To 2.5	0.1-10	To 2	To 3	7.5

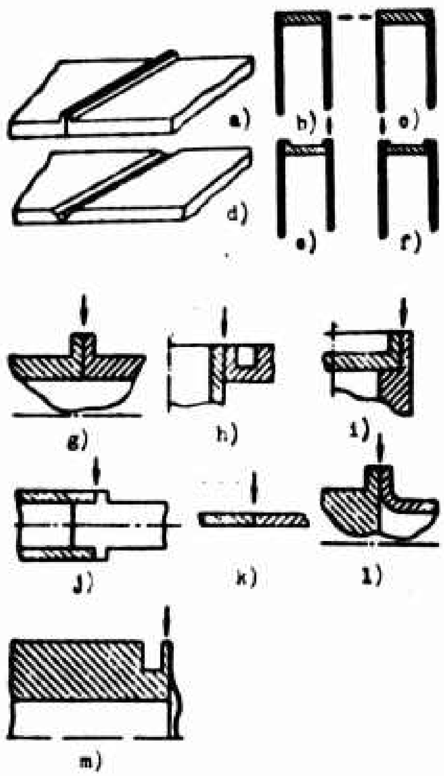


Fig. 50. Types of welded joints recommended in electron-beam welding. Pointer shows direction of electron beam on edges.

Electron beam can be applied with success also for welding of heterogeneous metals. In particular welding of aluminum and copper is possible. Here, spot of beam is disposed 2/3 on copper and 1/3 on aluminum [39]. Joint obtained is of soldered type, copper is practically not melted. During welding of copper with steel with small overlap, at first the motionless beam melts the copper, and then welding follows.

Tentative conditions of welding of certain metals are given in Table 73.

Electron beam welding ensures high quality of joint of metals, tanks to decrease of size of grains in seams, porosity, and also danger of formation of cracks. This is especially important during welding of refractory, high-heat-conducting and highly active metals which do not lend themselves to joining by usual methods of welding. In particular, during welding of molybdenum, it is possible to substantially increase ductility of welded joints as compared to welding in medium of argon or helium.

In Table 74 are given data on mechanical properties of welded joints of certain metals, carried out by electron beam.

Table 73. Tentative Conditions of Electronic-Beam Welding

Welded metal	Thickness in mm	Type of joint (Fig. 50)	Accelerating voltage, in kv	Current of beam, in ma	Speed of welding in m/hr	Geometric parameters of seam		Source
						Ratio of depth of melting to width of seam	Width of zone of thermal influence, in mm	
Molybdenum VM1...	1.0	k	18-20	60-80	60-75	1/1.2	0.8	[32]
Molybdenum (unalloyed).........	1	k	18-20	70-90	60	—	—	[41]
	2		20-22	100-120	40	—	—	
	3		20-22	200-250	30	2/1	3.1	
Molybdenum (0.5 Ti)............	1.27	k	130	4	42.5	1/1	0.4	[18]
Tantalum.........	0.5	k	18-20	65-75	50-70	—	—	[32]
Titanium unalloyed	1.0	k	18-20	85-100	60-80	—	—	[32]
Constantan.......	1.5	k	18-20	80-90	55-70	—	—	[32]
Kovar............	1.0	k	18-20	70-90	60-70	—	—	[32]
Niobium..........	1.0	k	18-20	85-100	40-60	—	—	[32]
Copper, MB.......	1.0	k	18-20	100-120	60-70	—	—	[32]
Copper M1........	1.0	k	30	30-35	2.68 to 2.75	4.5/4	—	[32]
Bronze, BRKh + + titanium.....	1.35 + 1.0	k	18-20	90-100	50-60	—	—	[32]
Nickel..........	1.0	k	18-20	80-90	60-70	—	—	[32]
Steel 1Kh18N9T...	1.5	k	18-20	90-100	70-80	—	—	[32]
Steel EI696......	9	k	20	120	35	5/1	—	[24]
Armco iron.......	1.5	k	18-20	90-100	60-70	—	—	[32]
Molybdenum + + titanium.....	1.0 + 0.5	e	18-20	70-90	60-70	—	—	[32]
Porous tungsten + + molybdenum...	1.0 + 0.2	f	18-20	45-50	50-60	—	—	[32]
Tantalum.........	0.15 + 0.1	e	18-20	30-40	70-80	—	—	[32]
Molybdenum + + tantalum.....	0.15 + 0.15	e	18-0	30-40	60-80	—	—	[32]
Zirkaloy 2.......	6.35	k	100	8	21.5	4/1	—	[34]
Dispersion-hardening, heat-resistant steel	3.2	k	140	4.5	42.5	3/1	1.6	[40]
Titanium alloy (13V-11Cr-3A1)	3.2	k	135	6.5	42.5	3/1	1.1	[40]

Table 74. Mechanical Properties at Room Temperature of Joints Welded by Electron Beam (Conditions of Welding Correspond to Table 73)

Weldable metal	Indices of mechanical properties						Source
	Ultimate strength, in kg/mm^2	Yield point in kg/mm^2	Relative elongation, in %	Hardness, Rockwell			
				Base metal	Zone of thermal influence	Seam	
Steel Kh10CrNiNb189	61.8	—	40.3	—	—	—	[44]
Dispersion-hardening heat-resistant steel*	— 93.6	— 78.9	— —	31 31	31 81 (B)	27** 89 (B)***	[40]
Titanium alloy (13V-11Cr-3Al)	99.0 135.7	99.0 122.1	15.4 4.9	33 42	33 42	35**** 42*****	[40]
Molybdenum alloy (0.5 Ti)	69	55	—	28-30	91-96 (B)	96 (B)	[40], [41]
Zirkaloy-2	65-70	~50	15-20	—	—	—	[34]

*Composition (in %): C — 0.05; Mn — 1.20; Si — 0.63; Cr — 15.1; Ni — 26.2; Mo — 1.30; V — 0.26; Ti — 2.30; Fe — remaining.

**In annealed state before welding, and subsequent heat treatment for optimum durability.

***In strengthened state prior to welding with subsequent tempering.

****Without heat treatment after welding.

*****Double heat treatment for aging.

Ultrasonic Welding

Essence of process and field of its application. For formation of a nondetachable joint during welding by ultrasonics, use is made of mechanical energy of ultrasonic oscillations, applied in zone of contact of tightly held components. Shear strains appearing in contact destruction of brittle surface films and local heating, but under influence of compressing stresses there occurs plastic flow of metal, necessary for formation of joint. Temperature in contact between components usually does not exceed several hundred degrees (200-300° during welding of aluminum, 600° — during welding of copper).

Advantages of ultrasonic welding are as follows:

1) comparatively small thermal influence on welded metals;

2) possibility of welding heterogeneous materials, and also thin sheets and foil in stacks or with components of unlimited thickness;

3) absence of necessity to thoroughly clean weldable surfaces;

4) small compressive forces and preservation of practically constant section of material in zone of welded point or seam (dent not more than 5-10% thickness of sheet);

5) insignificant deformations;

6) small capacity of welding equipment and simplicity of its construction. Consumption of electric power during ultrasonic welding constitutes approximately 10% of consumption during contact spot welding.

At present, ultrasonic welding is applied in instrument building and the radioelectronic industry, in the aviation industry and automobile construction for welding of thin elements to supporting constructions in precision machine building, in the electrical industry (welding of contacts) and in other branches of industry.

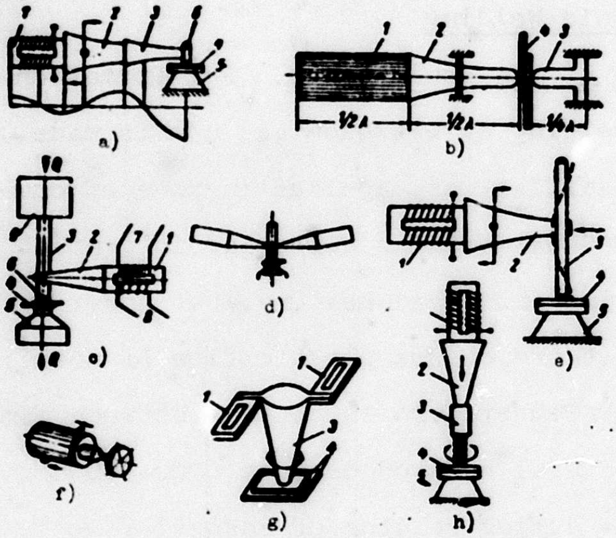


Fig. 51. Diagrams of transmission of ultrasonic oscillations to welded components: a and b — from longitudinally-fluctuating tool, located parallel (a) and perpendicular (b) to welded surface; c and d — through tool, loaded by connected mass and accomplishing bend oscillations with one converter (c) and with coupled converters (d); c and f — through link, accomplishing bend oscillations, with free end of tool during point (e) and roller (f) welding; g — by means of revolving magnet; f — through tool with spiral threading; 1 — motor of magnetostrictive converter; 2 — transformer of longitudinal elastic oscillations; 3 — tool; 4 — welded component; 5 — support; 6 — tip; 7 — winding of magnetizing current; 8 — winding of high-frequency current; 9 — connected mass.

Ultrasonic oscillations can be used also for influencing the process of crystallization of metal of welded electroslag seams for the purpose of reducing their tendency to form hot cracks [2].

Possible diagrams of transmission of oscillations by welded components are shown in Fig. 51 [30]. In Fig. 52 is depicted seam variant of ultrasonic welding. At present, diagrams of Fig. 51a, b and d are used in practice. Diagram with transmission of oscillations normally to surface of article is used only for welding of plastics.

Equipment. As a source of ultrasonic oscillations, use is made of a magnetostrictive converter, constituting a pack of stamped plates of 0.1-0.2 mm thickness (magnetic conductor) with the winding. Oscillations are transmitted through transformer of longitudinal oscillations or through tool, joined to magnetostrictive converter by soldering with a solid solder. Length of tool is equal to integer of half-waves of ultrasonic wave (see Fig. 51a).

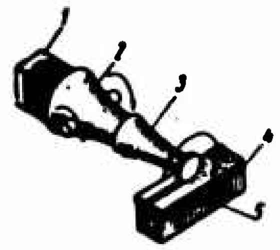


Fig. 52. Diagram of seam ultrasonic welding (designation of positions the same as in Fig. 51).

Depending upon assignment, one uses cylindrical, stepwise, conical, exponential and catenoidal transformers of longitudinal oscillations [29].

Converter is fed from a special generator of high frequency with smooth adjustment of current frequency. Above are given technical specifications of generators most frequently applied for feeding converters of ultrasonic welding machines [6], [16].

Technical Specifications

	Type of generator			
	UZG-2.5	UZG-5	UZG-10	A624-12
Input, in kilowatts..............	6.5	12	20	1.6
Output, in kilowatts.............	3	6	9.5	0.5
Nominal output voltage, in v.....	400	400	500	–
Limits of frequency change, in kilocycles per sec............	18-25	18-25	18-25	15-30
Types of transmitting tubes in terminal power amplifier......	TU-5A	TU-5A (two)	TU-10A	TM-70 (four)
Feed voltage, in v...............	220/380	220/380	220/380	220
Overall dimensions, in mm:				
length	560	650	790	540
width	790	780	780	520
height	1400	1500	1840	1150
Weight, in kg....................	410	500	620	185

Welding tip directly transmits load and vibration to weldable surfaces. It is recommended to prepare it from materials with small conductivity and high resistance to shear at height temperatures. For welding of aluminum and its alloys, tips are made of steel 45 or ShKh15. Height of tip, depending upon conditions of approach to place of welding is 12-40 mm. Force, necessary for compression of details, is created by a hydraulic or pneumatic system. Magnitude of

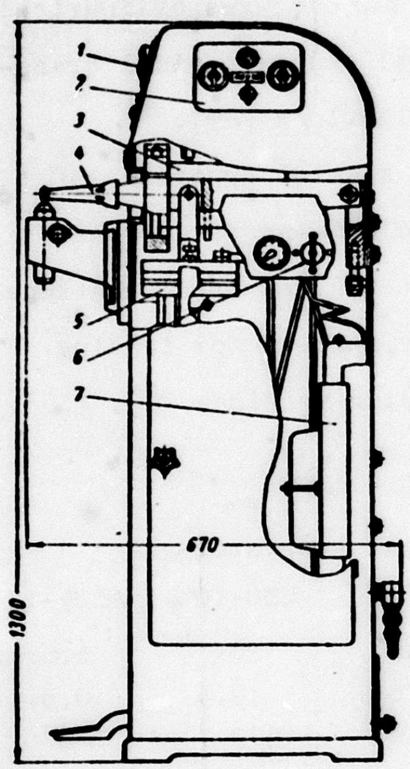


Fig. 53. Diagram of unit UZSM-1: 1 — control panel; 2 — electron time relay; 3 — holder; 4 — welding tool with tip; 5 — pneumatic device; 6 — air pressure regulator; 7 — air distributor with electromagnetic drive; 8 — support.

force is regulated usually within limits of 0-300 kilogram.

In Table 75 are given characteristics of certain domestic units of industrial type for ultrasonic welding [29], [30].

Limits UZSM-1 (Fig. 53) and UZSM-2 (Fig. 54) with a longitudinally fluctuating tool are intended for welding of small-size components under stationary conditions. For creation of ultrasonic mechanical oscillations in them, use is made of a magnetostrictive converter of type PMS-15.

Apparatus UZSA-3 is portable and is intended for one-side welding of thin sheets to thick components. Its basic advantage is possibility of welding under installation conditions. Welding head (Fig. 55) is secured on component with help of vacuum suction.

Welding-assembly table I020-019 with tool, accomplishing bend oscillations, is used for precision welding of small articles in radioelectronic industry.

Abroad, ultrasonic welding machines are produced by firms "Gulton industry" and "Sonobond Corporation" (the United States), "Mullard Research Laboratories" in England and "Lehefeldt and Co" in West Germany [35], [36], [42], [43].

Table 75. Technical Specifications of Certain Industrial Units for Ultrasonic Welding

Characteristic	Type of unit						
	UZSM-1	UZSM-2	UZTSh-1	UT-4	UZSA-1	UZSA-3	I020-019
Capacity of magnetostrictive ultrasonic converter, in kw.....	2.5-4.0	2.5-4.0	4.0	4.0	2.5-4	1	0.5
Working frequency in kc	19.5	19.5	20	20	20	22	14-19
Limits of adjustment of contact force, in kg..	20-200	20-140	10-200	5-200	0-300	5-20	2-40
Limits of adjustment of welding time, in sec.	0.1-4.0	—	0.2-8	0.1-2.0	0.25-5	—	0.2-5.7
Type of drive creating contact force.......	Pneumatic	Lever mechanical	Pneumatic	Lever mechanical	Pneumatic	Lever	Lever mechanical
Speed of welding, in m/hr................	—	4.5-150	4.5-145	—	—	—	—
Useful extension of welding tool, in mm.	75	135	130	130	—	—	—
Consumption of air, in m^3/min.............	0.003	—	0.005	—	—	—	—
Consumption of water, in liters/min.......	3	3	3	3	—	—	—
Overall dimensions, in mm:							
height	1250	1320	1440	1020	630	150	1300
width	430	490	570	635	410	180	670
length	670	950	745	680	685	750	1000
Weight in kg..........	120	200	240	70	55	8	105
Source of feed (generator)...............	UZG-2.5 or UZG-5		UZG-5 or GUZ-58		UZM-10	UZT-2.5	A621-12
Assignment...........	For spot welding	For seam welding	For point and seam welding	For spot welding		For spot welding of components with large or shaped surfaces	For precisian-spot welding

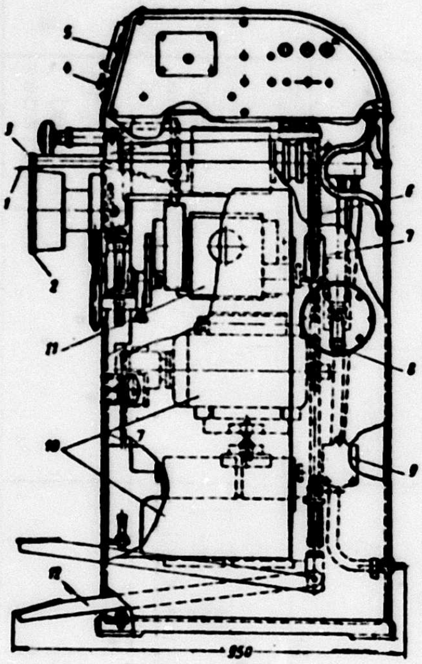


Fig. 54. Diagram of unit UZSM-2: 1 — weldable components; 2 — lower roller; 3 — upper roller; 4 — potentiometer; 5 — control panel; 6 — spring; 7 — scale; 8 — handle; 9 — final switch; 10 — drive; 11 — reducer; 12 — pedal.

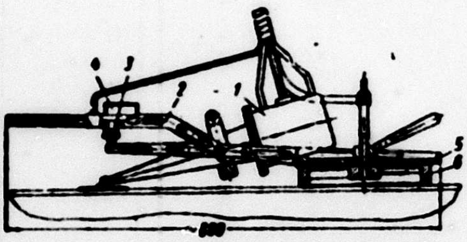


Fig. 55. Diagram of welding head of unit UZSA-3: 1 — converter; 2 — level device; 3 — spring; 4 — final switch; 5 — bracket; 6 — vacuum suction.

Technology and parameters of conditions of welding. Strength of welded joints. Weldability of metals by ultrasonics is different. The best to weld are aluminum alloys, copper, titanium, stainless steels and many plastic materials. Ultrasonic welding is used also for joining of molybdenum, niobium, tantalum, zirconium, difficult to weld by usual methods, and also for joining of metals in heterogeneous combinations, for instance titanium and aluminum with stainless steel, nickel with molybdenum, titanium with stainless steel and so forth. Here welding is carried out easier the closer the hardness of the weldable metals.

In Fig. 56 are given data on weldability of metals with ultrasonics in different combinations [30]. Absence of indications of weldability (absence of sign) does not exclude possibility of welding of given combination of metals.

Types of joints and assemblies applied in ultrasonic welding are

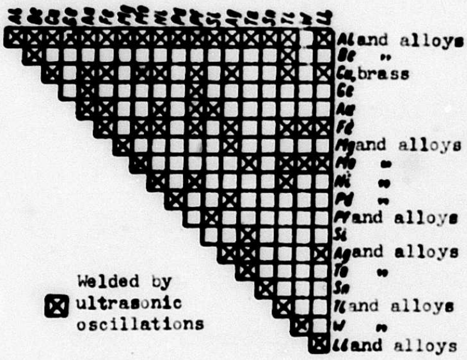


Fig. 56. Weldability of different metals and their alloys by ultrasonics.

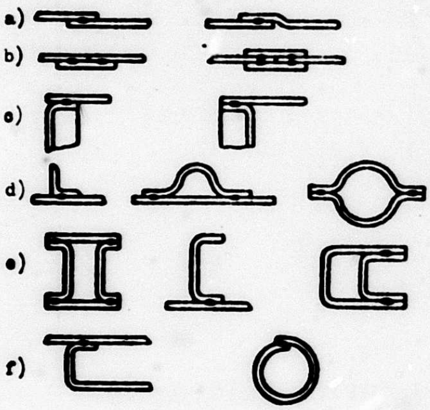


Fig. 57. Types of welded joints and assemblies during ultrasonic welding: a) overlapping without hewing and with hewing; b) joint with one-side bilateral cover plate; c) flanging, internal and external; d) welded assemblies of open type; e) welded assemblies of half-open type; f) welded assemblies of semi-closed and closed type.

shown in Fig. 57. The most simple ones are assemblies of open and half-open type. For welding assemblies of complicated form and, in particular, closed ones, special equipment is used.

Before welding, surfaces of components in place of joint are cleaned from dirt and fats. It is possible to weld articles with oxidized films (anodized aluminum) or with insulating coatings without preliminary cleaning.

Basic parameters of conditions of ultrasonic welding are: force at contact P, time of welding τ, freqeuncy f and amplitude A of elastic oscillations.

There exist certain optimum values of parameters P, τ and A, corresponding to maximum values of strength of joint.

Too large a contact force evokes increase of surface strain. Below a certain minimum value of this force, welding in general, does not occur, since forces of elasticity of metal are not surmounted and a tight contact between weldable surfaces does not form.

For small duration of welding, joint will form only in separate points of contact and strength of welded point will be small. If

duration of welding exceeds optimum, surface of component in place of introduction of ultrasonic oscillations strongly is deformed and there is possible formation of internal or external cracks, which also leads to lowering of strength of joints.

Amplitude of oxcillations has optimum value for every material and thickness. For smaller values of amplitude, strength of joint decreases or joint, in general, will not form. For excessively large stresses, there is possible destruction of joint, which has a fatigue nature. Minimum value of amplitude of oscillations A necessary for welding, is determined by the formula [29]

$$A = \frac{S}{G}(\delta_1 + \delta_2),$$

where δ — thickness of welded components;

S — cutting stress on boundary of plates;

G — shear modulus of material of plates.

Frequency of elastic oscillations applied during welding by ultrasonics, constitutes from 15 to 70 kc.

In Table 76-78 are given recommended conditions of ultrasonic welding of certain metals and their alloys, and also data on strength of welded joints.

Besides joining of metals, ultrasonic oscillations are used for welding of plastics.

Table 76. Conditions of Ultrasonic Welding of Certain Metals and Alloys [29]

Material	Thickness in mm	Parameters of conditions			Tip	
		P in kg	τ in sec	A in μ	Material	Hardness
Aluminum	0.3-0.7 0.8-1.2 1.3-1.5	20-30 35-50 50-70	0.5-1.0 1.0-1.5 1.5-2.0	14-16 14-16 14-16	Steel 45	HV 160-180
Alloy AMg6 Alloy AMg3M	0.3-0.5 0.6-0.8	30-50 60-80	1.0-1.5 0.5-1.0	17-19 22-24	Steel 45	HV 160-180
Alloy D16AM	0.3-0.7 1.1-1.3 1.4-1.6	30-60 90-100 110-120	0.5-1.0 2.0-2.5 2.5-3.5	18-20 18-20 18-20	ShKh15	HV 330-350
Alloy D16AT	1.1-1.3 1.4-1.6	110-120 130-150	2.5-3.0 3.0-4.0	20-22 20-22	ShKh15	HV 330-350
Copper	0.3-0.6 0.7-1.0 1.1-1.3	30-70 80-100 110-130	1.5-2 2-3 3-4	16-20 16-20 16-20	Steel 45	HV 160-180
Titanium AT3 Titanium AT4	0.25 0.5	40 60	0.25 1.0	16-18 18-20	Hard-facing with electrodes T-590	HRC 60
Titanium VT1	0.5 0.8 1.0	80 90 120	0.5 1.5 1.5	20-22 22-24 18-20	VK-20 Hard-facing with electrodes T-590 VK-20	— HRC 60
Zirconium	0.5	90	0.25	23-25		
Nickel	0.1	50	1.0	—	—	—

Note: Radius of sphere of tip 10 mm.

Table 77. Strength of Joints of Certain Metals and Alloys, Carried out by Spot Ultrasonic Welding [29], [30]

Material	Thickness in mm	Destructive force during test for extension - shear in kg	Material	Thickness in mm	Destructive force during test for extension - shear in kg
Aluminum A1	0.5 1.0 1.5	53 103 150	Copper	0.05-0.06 0.5 single-spot, 0.5 two-spot 1.0	6.6 113 267 224
Alloy D1AM	0.5	74			
Alloy AMg6	0.5	109	Titanium AT3	0.25 0.65	73 410
Alloy AMg3	0.8	108	Titanium AT4	0.25 0.5	81 184
Alloy D16AM	0.5 1.0 1.2 1.5	75 220 250 236	Titanium VT1	0.5 0.8 1.0	220 330 293
Alloy D16AT	1.0 1.5	163 170	Zirconium	0.5	70
Alloy D16AT anodized	0.4 0.6 0.8 1.0	59 110 153 186	Brass L62	0.23	42
			Steel 1Kh18N9T	0.1 0.2	35 60
			Nickel	0.1-0.005	61

Table 78. Conditions of Ultrasonic Welding of Metals in Heterogeneous Combinations and Strength of Welded Joints [29]

Weldable materials	Thickness in mm	Parameters of conditions		Magnetizing current of vibrator, in a	Destructive force during test on extension — cut in kg
		P in kg	τ in sec		
Copper + stainless steel	0.1 + 0.1	100	0.75-1.0	20	16-18
Copper + titanium.......	0.1 + 0.6	100	1.0	20	16-18
Brass L80 + copper......	0.4 + 0.1	100	1.0-1.5	20	35-40
Brass L80 + L80.........	0.4 + 0.4	100-150	1.5-2.0	20	100
Duralumin, plated D16AT + D16AT.........	1.0 + 1.0	200	30-35	20	400-445
Nickel + titanium.......	0.1 + 0.6	200	1.0	20	30-40
Nickel + brass L80......	0.1 + 0.4	100	1.0	20	30-40
Nickel + copper.........	0.1 + 0.1	50	1.0	20	25-35
Nickel + stainless steel	0.1 + 0.4	150	2.0	20	30-40
Alloys AMtsAП + AMg6M	0.5 + 1.5	200	2.0-2.5	20	110-120
Alloys AMtsAП + D16AT	0.5 + 1.0	150	1.0-1.5	20	110-120

Diffusion Welding in Vacuum

Essence of method and field of application. During diffusion welding, joint forms as a result of diffusion of elements of contacting pair of metals, to which is applied definite upsetting pressure. A distinctive peculiarity of process is the fact that weldable surfaces are heated somewhat higher than temperature of recrystallization, but applied residual pressures are comparatively small. This allows to produce welding with great degree of accuracy, without noticeable change of physico chemical properties of welded metals. Besides, there is no need for electrodes, fluxes, welding metals and so forth. Process is carried out in vacuum, thanks to which there is no oxidation of surface of welded components.

Method of diffusion welding possesses has very wide technological possibilities. It is possible to weld not only flat, but also conical (bodies of radio tubes), spherical (step bearings) and complicated relief (welding of facing layers) surfaces. In precision machine building and instrument building, diffusion welding of thin-walled rings and tubular elements, and in radiotechnical industry for welding of figure elements of printed circuits to plates. This allows to lower level of noise in printed circuits as compared to soldered joints.

With diffusion welding it is possible to obtain thermoresistant, vibration-durable and vacuum tight connections, which are especially important in instrument-building. Cleanliness of medium, in which welding is produced and comparatively low temperatures of heating assure high-quality joints of chemically-clean metals and precision alloys.

Equipment. Unit for diffusion welding consists of following main assemblies (Fig. 58): vacuum welding chamber 1, source of heating

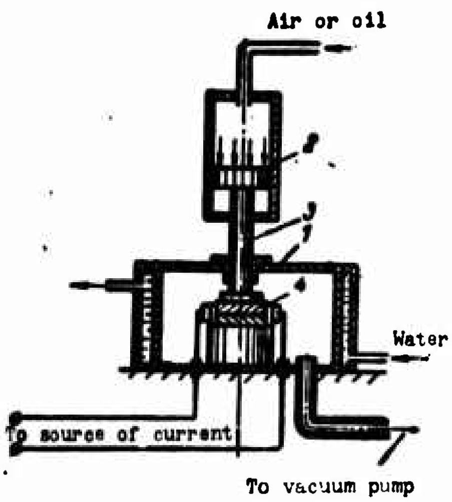


Fig. 58. Diagram of installation for diffusion welding: 1 — vacuum welding chamber; 2 — loading device; 3 — current; 4 — welded components.

of components, vacuum system, loading device 2, lever, pneumatic or hydraulic, instruments for measurement of temperature of components and vacuum in chamber. Vacuum in chamber is maintained at 10^{-3} to 10^{-5} mm of mercury column. Heating of components to temperature of welding starts after pumping out of air from chamber.

Depending upon use, we distinguish units for individual, series and mass production. The two last ones can be in the form of rotor machines or are supplied with devices for sluicing.

Control of units may be manual, semiautomatic or automatic.

At present, 19 types of industrial and semiindustrial specialized SDVU units have been developed and are being made. Overwhelming majority of them has induction heaters. In SDVU-5 units applied for welding of aneroid instruments-diaphragms, and also SDVU-16 and SDVU-7K intended for welding of tail tools, is made of resistance heating of components but in SDVU-14 unit for welding of thin-sheet components of up to 150 mm and height up to 160 mm — radiation heating.

Productivity of diffusion welding units for individual production with manual control constitutes, depending upon type of welded components, from 50 to 200 components per shift, and that of semiautomatic machines — up to 6000 components per shift.

Vacuum unit SDVU-2 has following technical specifications [15]:

temperature of heating 400-1300°, duration of welding 6-18 min, heating — induction, source of feed — vacuum-tube oscillator LGZ-10A, productivity 150 articles per shift.

Technology and parameters of conditions. Properties of welded joints. Basic conditions for obtaining quality joints are reliable contact between welded surfaces and uniform heating of components all over cross section. It is recommended to machine surface with a cutter to a cleanliness not lower than ∇6-∇7. Components of electrovacuum instruments are subjected to subsequent annealing in medium of hydrogen. Grinding decreases strength of components by 15-20%, which is explained by inclusion of abrasives. During chemical etching with subsequent washing strength characteristics of joint are stabilized.

After loading of components in chamber and achievement of required vacuum, one starts heating to given temperature; when temperature on cross section is even, pressure is applied, which is kept constant during all process of welding. Depending upon temperature of welding and kind of weldable metals, pressure can constitute 0.3-10 kg/mm^2, but as a rule, should not exceed 2.5 kg/mm. Excessive increase of pressure leads to lowering of strength of joint.

Holding time under load at a temperature of welding constitutes from several minutes to scores of minutes. With an increase of time of welding to a certain optimum value, strength of joint increases to ultimate strength of basic metal, but with a further increase of time, it drops as a result of growth of grain. Besides, indices of lengthening and impact toughness worsen. Increase of temperature of welding has an analogous influence.

In process of cooling of components after welding, the compressing

load is removed at temperatures of 100-400°, depending upon difference of coefficients of linear expansion of welded metals. Thanks to this, there is no possibility of destruction of joint from different thermal shrinkage of weldable details.

Diffusion welding is successfully used to connect refractory and chemically active metals, nonferrous metals (copper and aluminum), aluminum with copper kovar alloy, stainless steel, silver with stainless steel, bronzes among themselves and with stainless steels, molybdenum with kovar alloy and other metals. In production of electrovacuum instruments of super-high frequency, one uses welding of mineral ceramics with ferrous metals, kovar alloy and copper.

Conditions of welding of certain metals are given in Table 79 [15].

Table 79. Conditions of Diffusion Welding of Certain Metals

Welded metals	Welding temperature in °C	Pressure in kg/mm	Welding time, in min
Copper MB + copper MB..............	800-850	0.5-0.7	15-20
Kovar + kovar......	1000-1100	1.5-2.0	20-25
Steel 45 + steel 45	1000-1100	1-2.0	5
Brass P72 + brass P72.............	750	0.8	10
Alloy AMg6 + alloy AMg6............	500	0.2	20
Aluminum AD1 + + kovar.........	450	1-2	5
Silumin D1T + kovar 38KhN1-0A........	370	2.0	20
Aluminum AD1 + copper M1........	450	0.3	15
Copper M1 + kovar..	850	0.3	10
Copper M1 + steel 45..............	850	0.5	10

If during direct contact of weldable components, one cannot obtain metals or metals with nonmetallic materials a joint of satisfactory quality, one uses intermediate linings of a third metal, or so-called underlayers. Lining prevents formation of intermetallic compounds and promotes formation of a joint at lower temperatures.

Cold Welding by Pressure

Formation of joining during cold welding by pressure and criterion of weldability. During cold welding by pressure, a joint will form by means of joint plastic deformation of components. As a result of approach of clean surfaces of distance of action of interatomic forces between them, there appears a strong metallic connection.

Weldability of metals by cold method is estimated by degree of deformation, ensuring formation of a reliable joint.

Value of Deformation, Necessary for Formation of Reliable Joint (After Treatment of Surface with a Metal Brush) [31]

Metal	Deformation in %
Aluminum	60-70
Copper	85-90
Armco iron	85-92
Lead	55-85
Tin	86-88
Gold	30-35
Indium	10-15
Silver	50-86
Cadmium	80-86
Aluminum alloys	75-90
Titanium	70-75
Nickel	85-90

With cold welding, it is possible to connect only metals sufficiently ductile at room temperature. Weldability depends, furthermore, on relationship of hardnesses of metal and surface films. The greater the hardness of films, as compared to hardness of metal, the easier

their destruction during deformation, and consequently also formation of a joint.

Drop of strength of joint, as a result of a decrease in thickness of components in place of welding is compensated by cold working during deformation.

The widest use of cold welding is for joining aluminum and copper (reinforcing of aluminum wires by copper cover plates, manufacture of aluminum bodies of radiotechnical components, joining of fuses and wires). Welding is possible in case of other metals in uniform and heterogeneous combinations, in particular of aluminum and its alloys with lead, brass, cadmium, nickel; copper with steel of type 18-8, nickel, brass, iron and so forth.

<u>Technology of welding and applied equipment</u>. One of important conditions of obtaining a joint of good quality during cold welding is cleanliness of combinable surfaces. Surface film of oxides and contamination have to be removed. During welding overlapping stripping is produced by a wire brush, scraper, washing in solvents. Sometimes, components are heated in furnace or coated with hard and brittle protective coatings. Before butt welding, wire or rod is cut with scissors or cutting pliers, in such a manner that butt surface is perpendicular to axis of rod.

Diagrams of cold welding of overlapping metal of thickness from 0.2 to 15 mm are shown in Fig. 59 [1], [3].

Decrease of hollow during seam welding is attained by special assembly of sheets or preparation of their edges (Fig. 59e-h).

Width of punch b is selected from the formula

$$b = (1 + 3)\,\delta,$$

where δ — initial thickness of welded components in mm.

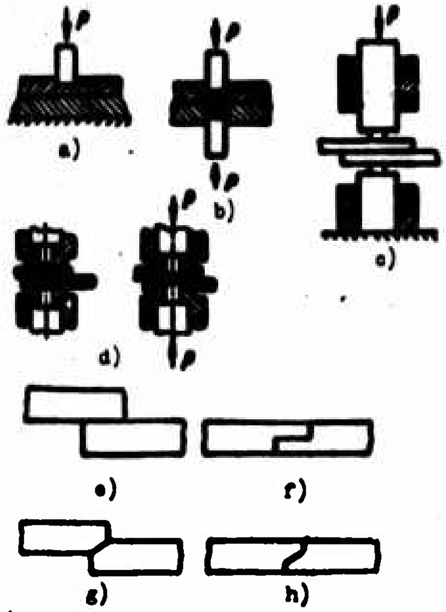


Fig. 59. Diagrams of overlapping cold welding: a) pressing in of one punch; b) pressing in of two punches of constant cross section; c) Pressing in of punches with collars; d) pressing in of punches with preliminary pressing components; e, f, g, and h) preparation of edges of sheets for seam welding without a hollow.

During welding of aluminum and certain of its annealed alloys, dimensions of rollers (diameter D, width b and height h of working projection) for seam welding are determined by the formulas

$$D = 50\,\delta;$$
$$b = (1 + 1.5)\,\delta;$$
$$h = (0.8 + 0.9)\,\delta.$$

Magnitude of deformation, necessary for formation of strong joint during spot and seam welding, depends on kind of metal and circuit of welding. As a rule, there exists a certain optimum magnitude of deformation, at which the biggest strength is attained.

Spot joints, carried out in accord with diagrams of Fig. 39a-b, possess a comparatively low strength. During welding by punches with collars with preliminary pressing of components, joint will form not only under the punches, but also in adjacent annular zone, as a result of which, strength is increased.

Conditions of welding and value of durability of single-spot welded joints of certain metals are given in Table 80. In Table 81 are given values of strength of butt welded joints of aluminum and aluminum with copper [4]. In Table 82 [31] is shown influence of subsequent annealing on strength of welded joints. Quality of joints during butt welding also depends on magnitude of deformation, which

Table 80. Conditions of Cold Welding of Certain Metals and Strength of Single-Spot Welded Joints

Material	Diameter of punch in mm	Thickness of material, in mm 2.0: Q in kg	2.0: Deformation in %	2.0: P in kg	1.5: Q in kg	1.5: Deformation in %	1.5: P in kg	1.0: Q in kg	1.0: Deformation in %	1.0: P in kg
Alloy AMtsA-M	3.5	3200	95	148	3000	88	130	—	—	—
	4.2	3000	92	160	3500	84	160	3050	89	104
	5.0	3800	92	210	4300	91	170	4100	87	112
	6.0	6000	91	230	—	—	—	—	—	—
	7.2	6000	87	300	—	—	—	—	—	—
Alloy AMgA-M	3.5	2500	85	125	—	—	—	—	—	—
	4.2	2600	88	180	—	—	—	3100	87	118
	5.0	4650	90	260	—	—	—	4200	85	120
	6.0	5600	89	310	—	—	—	—	—	—
	7.2	6000	84	340	—	—	—	—	—	—
Alloy D1AM	3.5	—	—	—	3800	87	90	3400	75	70
	4.2	3140	90	185	2750	84	120	3300	85	106
	5.0	—	—	—	4600	87	168	—	—	—
Alluminum A-2	3.5	1500	91	175	—	—	—	—	—	—
	4.3	2200	90	185	—	—	—	—	—	—
	5.0	3000	90	240	—	—	—	—	—	—
	6.0	3300	88	240	—	—	—	—	—	—
	7.5	4800	87	250	—	—	—	—	—	—

Note: Q – force of welding; P – average force of shear.

is regulated by length of extension of welded rods from clamps. Length of extension is selected by experimental means and is equal, on the average, to: 1 to 1.2 d for aluminum and 1.25 to 1.5 d for copper, where d – diameter or thickness of rod. During welding of heterogeneous metals, magnitude of extension of rods is unequal, in particular, during welding of aluminum with copper, extension for copper rod should be 30-40% larger than for aluminum.

Specific pressure and force of pressing are selected depending upon kind of weldable meta. During end-to-end welding aluminum, copper and copper with aluminum, specific pressures are equal, correspondingly to: 70-80; 200-250 and 150-200 kg/mm. Force of pressing during welding of aluminum is not less than 50% and during welding of copper – not less than 80% of upsetting force.

Table 81. Results of Mechanical Tests of Joints of Aluminum and Aluminum with Copper, Carried out by Cold Welding End to End

Material	Cross section of sample or its diameter in mm	Extension in mm		Relation of length of extension to diameter (thickness), in %		Test for extension	
		for copper	for aluminum	for copper	for aluminum	Force during break, in kg	Place of destruction
Aluminum	8	—	4	—	50	330-340	For basic metal
	10	—	5	—	50	600-620	
		—	6	—	60	590-620	
	12	—	6	—	50	820-860	
	20	—	7	—	35	2040-2140	
		—	8	—	40	2040-2140	
	10 x 20	—	7	—	70	1590-1720	
Aluminum with copper	8	6	4	75	50	—	
		6	5	75	62	—	
		7	4	88	50	—	
	10	7	5	70	50	—	
		8	5	80	50	—	
	12	8	6	67	50	—	
		8	7	67	58	—	
	10 x 20	13	9	130	90	—	
Note: Welding on machine MSKhS-35.							

Table 82. Influence of Subsequent Annealing on Strength of Single-Spot Welded Joints During Cold Welding

Metal	Conditions of annealing		Deformation, in %	Breaking load, in kg	
	Temperature, in ^{o}C	Time, in min		Prior to annealing	After annealing
Silver	700	4	79	36.3	90.8
Copper	700	1	82	18.1	88.0
Steel	800	1	80	0	90.8

During end-to-end welding of small, plastic materials, intermediate plastic linings are used.

A very important advantage during joining by cold-welding of aluminum buses and reinforcing of aluminum outlets by copper cover plates is the stability and reliability of the electrical contact in conditions of alternated heatings, high heatings in furnace or by a passing current and in chemically-active media [3].

Cold welding by pressure can be produced on any hydraulic and foot presses, creating necessary forces (up to 50-100 tons during multiple-spot welding). For this purpose, special attachments, consisting of matrix, punch, punch holder, clamp and fixing devices are used. However, application of presses in assembly production is not always economically expedient in connection with their small productivity.

VNIIESO has developed several types of special units for cold-welding with manual and semiautomatic control [31].

Unit UGKhS-5 with welding tongs serves for spot assembly welding of aluminum buses of 5 + 5 mm thickness. Force of welding (up to 5 tons) is created by a pneumatic-hydraulic drive. Productivity attains 400 weldings per hour, weight of tongs is 7 kg.

For reinforcing of aluminum components by copper cover plates, use is made of stationary machine MKhSA-50 with a pneumatic-hydraulic drive, developing a force up to 50 tons. Productivity of machine is 300 weldings per hour.

With help of semiautomatic machine MKhSK-1, aluminum bodies of capacitors with covers are welded. Limiting dimensions of body: diameter up to 50 mm or cross section 45 × 45 mm^2, height 85 mm. Pressing of details is carried out by a pneumatic device, but welding

force is created by a pneumatic-hydraulic converter. The machine is provided with a revolving table for feeding weldable components. Productivity during work under automatic conditions is 750 weldings per hour.

For butt welding of aluminum rods with a cross section up to 700 mm^2 copper up to 250 mm^2 and copper with aluminum up to 300 mm^2 machine MSKhS-60 is applied. Pressing of specimen and squeezing are carried out by a hydraulic device. Maximum upsetting force is 60 tons, pressing force 90 tons.

For cold butt welding of aluminum buses, aluminum with copper and trolley wires, a series of machines MSKhS-5, MSKhS-35 and MSKhS-30 have been developed, correspondingly with pneumatic and hydraulic drives [3].

For butt welding of aluminum and copper wires of small cross sections, use is made of manual tongs of several types constructed by the laboratory of Academy of Sciences of Latvian Soviet Socialist Republic, KS-6 construction by the laboratory of electrothermics of Institute of Electrical Engineering of Academy of Sciences of Ukrainian SSR, and manual attachment of type PS-7, Scientific Research Institute of the cable industry.

Welding by Friction

General information and basic parameters of process. During welding by friction of two weldable components, pressed one to another, a relative rotation is imparted. As a result of friction metal in zone of joint is heated to a plastic state and due to application to them of an axial compressing force, welding takes place.

Process of welding by friction is divided into three stages:

1) coarse working-in of rubbing surfaces, introduction and cut of roughnesses and unevennesses;

2) formation of clean surfaces as a result of destruction of brittle soiling films, occurring during significant plastic deformations;

3) liquid friction of clean surfaces, differing by intense growth of temperature and formation of local joints.

Coefficient of friction at the end of welding process attains 2-2.5, and temperature of butt — 1000-1200° [13].

Diagram of welding by friction is shown on Fig. 60.

Quality of joints during welding be friction is determined by four basic parameters of process: speed of relative rotation, axial force of compression of components, magnitude of upsetting and time of welding.

Speed of relative rotation can be modified within very wide limits. Besides, quality of welded joints is practically not changed and machine time of welding increases.

Axial force of compression, in the biggest degree, determines character of process. For many materials, welding is produced during a simple cycle of pressure, when heating and upsetting are carried out by a constant force of compression. However, specific pressure in process of heating and upsetting may be different. Step wise cycles of pressure are used: two-stage with high forge pressure and three-step, when heating starts at small pressure, then pressure in process of friction is increased, and upsetting occurs during high pressure. Sometimes, flux increases pressure. Sometimes pressure increases smoothly in process of welding.

Numerical values of specific pressures constitute from 2.5 kg/mm^2

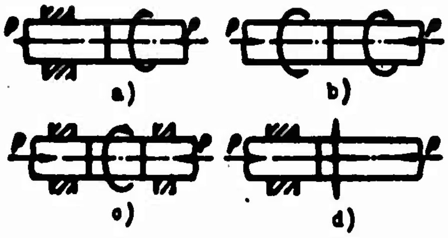


Fig. 60. Diagram of welding by friction: a) rotation of one component; b) rotation of two components; c) motionless components with revolving insert; d) reciprocating movement of one of components.

for soft and ductile materials to 25 kg/mm^2 for hard, special steels [7].

Magnitude of upsetting is established from conditions of removal of oxides and contaminations from joint in process of friction and guarantee of necessary strengthening in place of joining.

Welding time is determined by three first parameters and should be sufficient for heating butts of components to welding temperature.

Process of welding can be regulated by time and also by magnitude of upsetting.

Advantages of welding by friction include: the biggest capacity of welding machines, uniform load of network during use of induction drive motors, possibility of welding of metals in heterogeneous combinations, simplicity of equipment and ease of mechanization of process.

Welding by friction is used for end-to-end joining of rods of big cross section, for manufacture of round components with stepwise profile on length (axis, shafts, blank of bolts and gears), compound tool from heterogeneous metals, for joining comparatively thin pins and bolts with sheet material, for instance, in agricultural machine building, in production metal constructions and others.

Technology and conditions of welding by friction of homogeneous heterogeneous metals. Parameters of conditions of welding are established experimentally. Basic criterion during their selection is strength characteristics of welded joint.

Conditions of welding by friction of homogeneous metals and alloys are represented in Table 83, and heterogeneous – in Table 84 [7].

Table 83. Conditions of Welding by Friction of Homogeneous Metals and Alloys

Weldable material	Diameter of rods in mm	Relative speed of rotation in rpm	Specific pressure in kg/mm: during heating	Specific pressure in kg/mm: during upsetting	Magnitude of upsetting, in mm	Machine time of welding, in sec
Steel St. 3	20 40	1500 1000	5 10	5 10	5 12	5 20
Steel St. 5	16	1500	5	5	5	4.5
Steel 20 Steel 45 Steel 4Kh13	10	2000 1500	4 12	4 12	3 5 3–4	3 4.5 3
Steel 20Kh Steel 12KhN3A	12	800	4	4	4	4 3.5
Brass L62	16		3.3	3.3	6–7	3
Duralumin Copper	40	760 920	10 3.15	10 3.15	20	12 30
Aluminum AD-1	20 40	3000 760	0.8 3	0.8 3	6–7 20	3 10
Steel 38KhMYuA and 30 KhGS	10	1500	10	10	4	2

Table 84. Conditions of Welding by Friction of Heterogeneous Metals

Weldable materials: 1	Weldable materials: 2	Diameter of rods, in mm	Relative speed of rotation in rpm	Specific pressure in kg/mm^2: during heating	Specific pressure in kg/mm^2: during forging	Magnitude of upsetting, in mm	Machine time of welding, in sec
Steel R9	Steel 45	18	1800	11	11	4	12
Steel R18		13		13	13	6	6
Brass LMts58-2	Steel 20	20		2.5	2.5	6–8	8
Steel St. 3	Steel 45	12		3.5	3.5	6	5
Steel 1Kh18N9T		20	3000	8	8	7	3
Steel Kh12M						20	4
Bronze AMts9-2	Steel 20		1500	3.5	3.5	6–8	8–9
Copper	Aluminum	8	1350	2–3	10–20	–	10–20
Steel pin	Sheet of thickness 2.5 mm	10	3000	5	5	3	1.5
Copper pin	Sheet of thickness 2.0 mm		6000	1	6	1.5	2

It is necessary that weldable components have clean and unlubricated butt surfaces, perpendicular to axes of rotation. Series of identical welded components should be processed on surface of friction to identical cleanliness. Stripping of lateral surfaces, adjacent to faces, is not obligatory.

In Table 85 are given mechanical properties of welded joints, carried out by friction welding [7].

Equipment. For welding by friction, one can use, after corresponding modernization, practically any lathes, and also drilling and milling tools. However, due to significant vibrations in first stage of process of welding, machine tool can fail rapidly. Furthermore, on metal-machining tools, the instantaneous stoppage of rotation before upsetting is not attainable.

Table 85. Mechanical Properties of Welded Joints During Welding by Friction

Weldable materials	Ultimate strength during extension, in kg/mm²		Angle of bend, in degrees	Impact toughness, in kgm/cm²	Hardness HB	
	basic metal	welded joint			basic metal	seam metal
Steel St. 3	50	50*	180	8	112	140
Steel 20	43	43*	180	1.1	-	-
Steel 45	52	52*	90	2.5	-	-
Steel 20Kh	45	45*	180	4	-	-
Steel 40Kh13	70	70*	180	-	186	156
Steel 12KhN2A	64	64*	180	8	-	-
Steel R9 + steel 45		44.7	-	-	-	-
Steel R18 + steel 45	-	55	-	-	220	700
Brass LMts 58-2 + steel 20	-	35	90	-	-	-
Brass L62	54	48	180*	12	70	60
Bronze AMts9-2 + steel 20	-	50	70	-	-	-

*Destruction along basic metal.

VNIIESO has created special machines for welding by friction and has developed a scale of their dimensions [7]:

Dimension of machine	0	I	II	III
Diameter of welded cross section (carbon steel, in mm........................	Up to 10	8-25	20-40	35-60
Axial force, in kg..........	Up to 1000	4500	10000	30000
Speed of rotation, in rpm...	2000	1500	1000	500
Input during welding (tentatively), in kw............	Up to 3	10	20	60

Brief technical specifications of machines are given in Table 86.

Table 86. Technical Specifications of Machines for Welding by Friction

Characteristic		Type of machine: MST-1	MST-2	MST-3	MST-4	MST-2 modernized
Use		For welding of blanks of cutting tool		For welding of rod blanks	For manufacture of blanks of axes of rollers of ribbon transformers	For welding levers of gear box of tractors
Capacity of electric motor, in kw		10	10	20	4.5 × 2	7
Speed of rotation of spindle, in rpm		1430	1430	1 000	2 spindles, 1430	1500
Type of drive of of axial force		Pneumatic		Hydraulic	Pneumatic	
Maximum axial force, in kg		4500	4500	10 000	1600	8000
Dimensions of weldable details	Diameter, in mm	10—22 (steel R9 and steel 45)	12—25 (low-carbon steel)	20—40 (low-carbon steel)	12-14 (low carbon steel)	–
	Cross section in mm^2	–	–	–	–	400
Productivity, in weldings/hour		150	75	–	1500 pair of joints per shift	200
Type of clamps		Tongs	Chucks		Tongs	Chuck, self-centering

Welding by Currents of High Frequency

Diagrams and conditions of welding of longitudinal seams of pipes by currents of high frequency. By heating with currents of high frequency it is possible to weld pipes (longitudinal seams),

sheet metal and other articles from carbon and stainless steels, aluminum, copper, titanium, bronze, melchair and so forth. Metals welded have a thickness from 0.1 to 10 mm and more. As sources of feed electrical generators are used with a capacity up to 200 kva and a frequency up to 450 kc.

Longitudinal seams of pipes can be welded simultaneously on all the length by heating with conductivity current (Fig. 61a) and consecutively, by means of local heating with current of high frequency (Fig. 61b and c) or conductivity current (Fig. 61d).

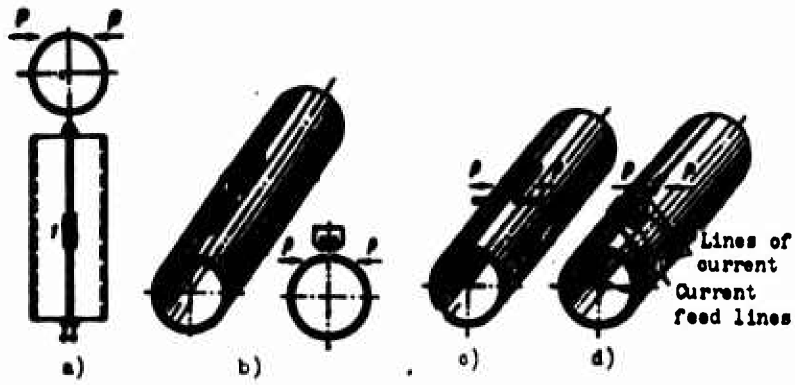


Fig. 61. Diagrams of welding of edges of pipes: a) simultaneous, with heating by conductivity current; b) consecutive, with heating by induced current with help of flat inductor with iron core; c) the same, with help of loop inductor; d) consecutive with conductivity current.

Best results of simultaneous welding of longitudinal edges of pipes are attained during heating with a current of frequency of 2500 cps during 15-20 sec to a temperature of 1350-1400°. For tighter compression of edges, one uses preliminary pressing with pressure of 1-1.5 kg/mm^2, pressure during upsetting, depending upon brand of steel amounts to 5-15 kg/mm^2. Specific power is equal to 200 kilovolt amperes per running meter of pipe.

Conditions of consecutive welding of pipes are given in Table 87 [38].

Table 87. Industrial Conditions of Welding of Pipes

Characteristics	Diameter of pipes, in inches	Thickness of wall, in mm	Capacity, in kva	Speed of welding in m/min	Frequency, in cps
Low-carbon and medium-carbon steel	2 1 1/2 1/2 2 8 3/8	0.51 3.81 1.25 1.65 3.59	200 600 250 250 130	61 45.5 7.6	4 8.3 10
Welding iron	1	0.3	35	23	450
Aluminum	1 4 1	1.27 1.24 1.24	50 19 17	30.4 49 61	
Stainless steel 302	1	1.62	26	20.7	
Brass 70/30	1 1/2	0.89	16	45.7	

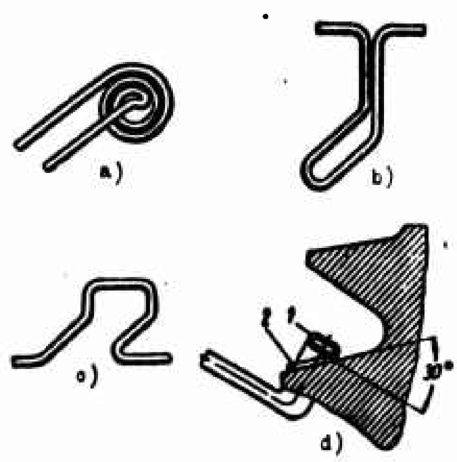


Fig. 62. Types of inductor a-c and diagram of reinforcing of teeth of boring bits d: 1 — inductor; 2 — briquette of hard alloy.

Inductors can be of multiturns and embrace the entire pipe, flat with an iron core and loops. In a number of cases, one installs additional inductors for preheating of weldable edges.

Hard-facing of hard alloys. For local induction heating during hard-facing of hard alloys, one applies on teeth of cutters of boring bits [21] single-turn and spiral inductors (Fig. 62a-c). On Fig. 62d is shown diagram of reinforcing of teeth with hard alloy "relit," which was first sintered in mixture with calined boric acid into a briquette 4 mm thick corresponding to shape of tooth of cutter.

Vibration-Arc Hard-Facing

Essence of process; equipment.

Vibration-arc hard-facing is used for applying thin films of metal (0.3-1.5 mm) during restoration of worn-out external surfaces of cylindrical components (surface of shafts, semiaxles, fitting surfaces under bearings and others) diameter 8-10 mm and above. Advantages of vibration-arc hard-facing are as follows: insignificant deformations of articles, high hardness of surface without additional heat treatment, simplicity of equipment and high productivity.

Application of metal is carried out in a stream of liquid and consists in periodic welding to surface of small particles of electrode wire. Fundamental diagram of unit for vibration-arc hard-facing is depicted in Fig. 63.

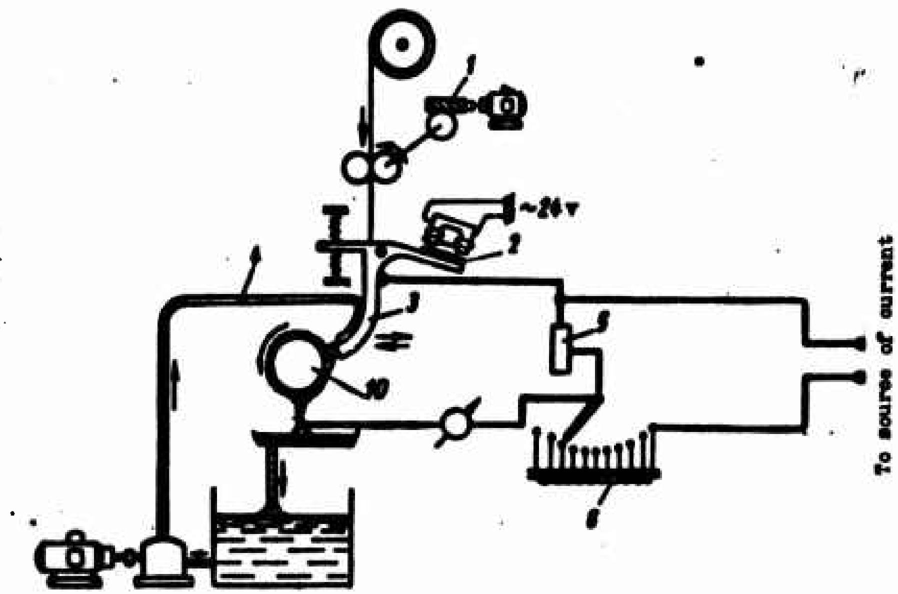


Fig. 63. Fundamental diagram of unit for vibration-ard hard-facing.

Automatic head of unit consists of feed mechanism of wire 1, vibrator 2, current-distributing mouthpiece 3 and device for feed and dosage of liquid coolant 4. If source of feed is selenium rectifiers, welding circuit includes a shunting resistance 5. Throttle 6 with sectionalized winding regulates the working current.

Liquid coolant is a 5% water solution of calcinated soda with addition of small quantity of technical soap. Head is installed on support screw cutting of engine lathe and machined component is braced in its chuck.

Number of turns of spindle of machine tool should be regulated from 0.3 to 25 per minute. With this as a goal, additional reducers

are installed, lowering turns of spindle 20-40 times. Longitudinal feed should constitute from 1.25 to 3.0 mm/turn and be regulated in such a way that difference between adjacent values would not exceed 0.4 mm/turn. Capacity of electric motor of machine tool is 0.5-0.75 kw.

Vibration of electrode is carried out by an electromagnetic or mechanical vibrator. For certain types of heads, end of wire accomplishes circular movement.

Technical specifications of heads for vibration-arc hard-facing are given in Table 88.

Table 88. Technical Specifications of Heads for Vibration-Arc Hard-Facing

Characteristic	Type of head				
	ChTZ	KM-5	KUMA-5	ChPRZ-ChTZ	UANZh-5
Capacity of drive motor, in w.........	150	250	—	125	85
Feed of electrode.....	Lateral		Upper		Lateral
Type of vibrator......	Electromagnetic		Circular movement	Electromagnetic	
Ranges of adjustment of speed of feed of wire, in mm/sec.....	12.5-22	6.7-50	3.3-50	15.2-24	10-20
Diameter of wire, in mm..................	Up to 2.2	0.7-2.5	0.5-2	Up to 3	1.2-2

<u>Technology of vibration-arc hard-facing; property of applied metal</u>. Preliminary preparation of components for hard-facing consists in cleaning of surface from rust and contaminations and welding of surface defects (hollows, dents) with a depth of more than 2 mm with subsequent machining for removal of superfluous metal.

Sections adjacent to restored surface are covered for protection from drops by a creamy mixture of water glass and chalk, but key grooves, grooves and holes are closed by inserts of copper or graphite.

Selection of wire is determined by requirements for deposited layer. For building up layers of high hardness HRC 40-52 R-1 and OVS wire is recommended and for obtaining a layer of hardness HRC 20-40 — 30KhGSA and 12KhM wire. During hard-facing with low-carbon wire (to 0.20%C), hardness of fused layer was equal to HB 170-270.

Diameter of electrode wire is selected depending upon required thickness of deposited layer (Table 89) [28].

Table 89. Diameter of Electrode Wire vs. Thickness of Deposited Layer

Thickness of layer,	Diameter of wire,
Less than 1	1-1.5
1-2	1.5-2.5
2 and more	2-3

Basic parameters of process of vibration-arc hard-facing are: Welding current, voltage of arc, linear speed of shift of processed surface, speed of feed of electrode wire, amplitude and frequency of oscillations.

Amplitude and frequency of oscillations are established, correspondingly, within limits of 0.75-1.0 d and 25-100 cps, where d — diameter of wire. Smaller values of amplitude correspond to voltage of arc.

Hard-facing is conducted with constant current of reverse polarity. Optimum value of voltage is equal to 10-13 v. Increase of voltage promotes increase of roughness and decrease of height of layer. Furthermore, losses in burning and spraying of electrode metal increase.

Inclusion in welding circuit of an induction resistance increases stability of process of hard-facing and lowers nonproductive loss of electrode metal to 6-7%. Thin layers of metal are applied with a small induction resistance (1-4 turn of throttle), and thick ones — with a large resistance (7-13 turns) [8].

Speed of shift of surface and speed of feed of electrode wire are mutually connected. Their relationship determines height of layer and its formation. Sagging of component during hard-facing should be not higher than 20-30% of thickness of deposited layer; oscillation of current and voltage, respectively — not higher than ±10 amp and ±0.3 v.

In Table 89a are given tentative conditions of vibration-arc hard-facing.

Table 89a. Tentative Conditions of Vibration-Arc Hard-Facing

Parameters of conditions	During low voltages	During voltages more than 15 v	Direct current from generator PS-300 with voltage of arc 20 v		
Diameter of wire, in mm	1.8-2.2	2.0			
Speed of feed of wire, in mm/sec	13-17	15-22	16	20	22
Welding current, in a	110-130	150-180	130	180	210

Treatment of Metals of Arc Plasma Stream

<u>Obtaining plasma stream and its characteristics.</u> If through

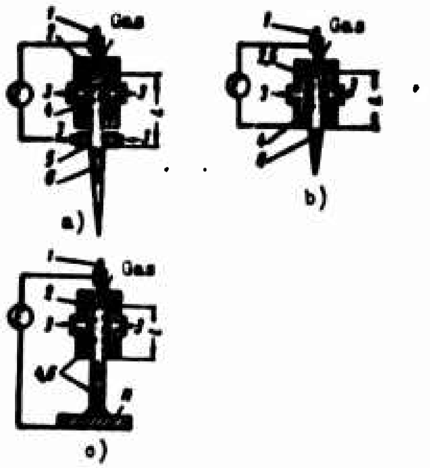


Fig. 64. Diagram of devices for obtaining a plasma stream: a) with separate nozzle and channel; b) with combined nozzle and channel; c) the same as b, but with stream coinciding with pole of arc; 1 — electrode; 2 — channel; 3 — cooling water; 4 — pole of arc; 5 — nozzle; 6 — plasma stream; E — source of current; И — article; l — deepening of arc in channel.

channel, inside which burns an electrical arc, one is to pass any kind of gas, then the latter is ionized as a result of collision with electrons and emerges from nozzle in the form of a brightly luminescent plasma stream (Fig. 64). Length of nucleus of stream, depending upon composition and consumption of gas, current and length of arc, form and dimensions of nozzle, can be changed from 2-3 to 40-50 mm, and temperature of stream attains 10,000-15,000°K [22]. Such a high temperature is obtained thanks to high density of energy in pole of discharge during its compression by flow of gas in channel.

Effective thermal capacity of plasma stream can be regulated by change of composition of gas, geometric parameters of channel and nozzle, current and voltage, and also distance from nozzle to article. In medium of helium, with addition of 14% argon, thermal capacity of stream is approximately 2 times higher than in medium of argon. Effective efficiency in plasma heating of article changes, thereby, insignificantly. On the average, effective efficiency of plasma stream is equal to 30-50%. Part of energy of arc, burning in nozzle, is expended on heating of nozzle and channel: from 25-30 to 60-70% for heads with separate stream, correspondingly, for large and small consumption of gas and from 5-6 to 30-40% for heads with stream coinciding with pole of arc.

Values of thermal capacity and effective efficiency of heating constitute for these two gas media, accordingly, 139 cal/sec and 30% and 75 cal/sec and 28%.

Types of plasma heads. Main assemblies of plasma heads are: nozzle, cooled by water; channel; electrode holder and body. For change of capacity of plasma stream, one can select a set of replaceable copper channels and nozzles with a different cross section of outlets. For adjustment of length of arc of head, there is a device, with help of which tungsten electrode is installed at various depths.

On Fig. 65a-c are shown heads constructed by the Institute of Metallurgy imeni A. A. Baykov, and in Table 90 are given their technical specifications.

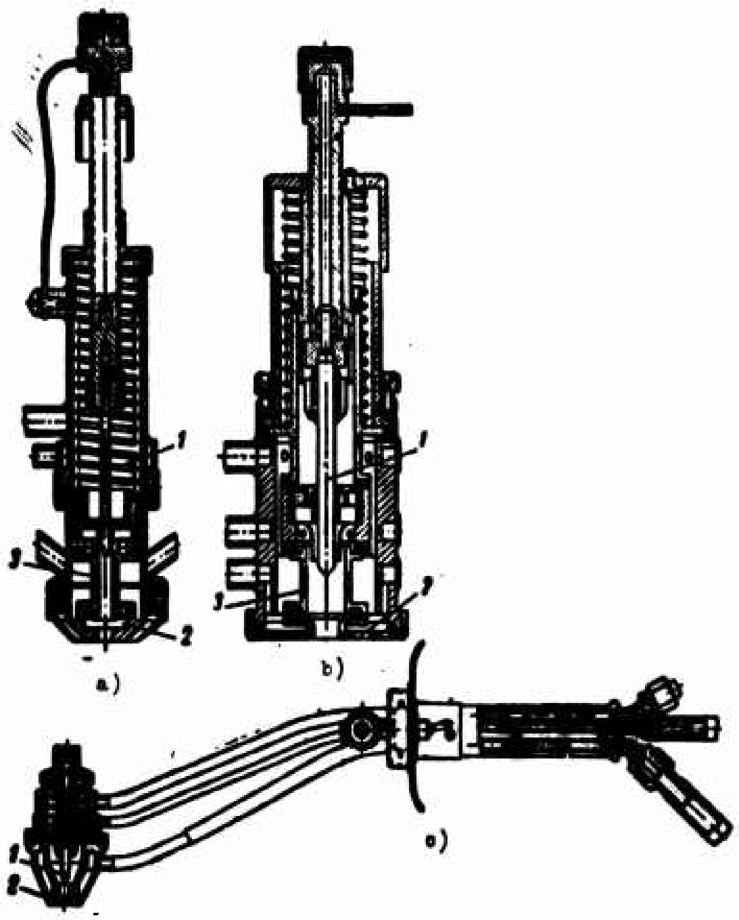


Fig. 65. Plasma heads: a) IMET-104; b) IMET-105; c) IMET-106; 1 – electrode; 2 – nozzle.

Table 90. Characteristic of Plasma Heads of IMET Construction

Type of head	Maximum capacity of head, in kw	Maximum current, in a		Head works in accordance with diagram	Diameter of nozzle, in mm	Length of channel of nozzle, in mm	Diameter of channel, in mm	Diameter of electrode, in mm	Deepening of electrode, in mm	Basic fields of application	Variant of performance	For automatic work	Weight, in g
		In accordance with diagram of Fig. 23a	In accordance with diagram of Fig. 23b										
IMET-104	15	180	300	Fig. 23a, b and c	1.5-5	4	4-8	2-6	15-30	Welding, cutting	For automatic work	50 × 240	600
IMET-105	25	250	500	Fig. 23a b and c	1.5-6	5	6-10	4-8	15-27	Application of coatings, cutting, melting	The same	60 × 220	1400
IMET-106	15	—	300	Fig. 23b and c	3-5	5	—	4-6	10-12	Cutting	The same	50 × 110	Automatic 350, manual 1100

Electrical equipment of the post for plasma treatment consists of source of feeding of direct current, ballast rheostat, oscillator, starting and measuring apparatuses.

As sources of feed welding converters PS-300, PS-500, PS-1000 or rectifiers are used. Idling voltage of source of current should not be lower than 60-65 v for work with pure argon. During use of nitrogen, helium or hydrogen, it is necessary to use higher idling voltage.

Application of plasma stream for treatment of metals. Plasma stream can be applied for welding, cutting, hard-facing, soldering, application of coatings and heat treatment. Plasma stream is especially useful for welding of thin-sheet metal – steels, nonferrous and refractory metals. Along with high productivity and reliable protection of melting pool from interaction with air, there is attained good and stable formation of seam along thickness and length.

Preliminary preparation of sheets for welding consists in their cleaning and flanging of edges; welding is possible without flanging. For decrease of warping of sheets of thickness less than 1 mm, they are installed in a special attachment with clamps and with additional gas protection of reverse side of seam from oxidation.

Conditions of automatic end-to-end welding without flanging of edges are conducted in Table 90a.

During use of stream, coinciding with pole of arc, speed of welding is increased.

Table 90a. Conditions of Welding with a Plasma Stream

Material	Low-carbon steel; 0.6 mm	Stainless steel, 1Kh18N9T; 0.8 mm
Current, in amp.........	60	160
Voltage of arc, in v....	29	29
Diameter of nozzle, in mm....................	5	4
Consumption of argon, in liters/hour		
in nozzle...........	155	170
in cap..............	—	580
Distance of nozzle to article, in mm........	3	4.5
Speed of welding, in m/hr..................	10	12

OXYGEN AND ELECTRICAL CUTTING OF METALS

Cutting is called totality of methods of parting in a metal body (Fig. 66a). Productivity of through cutting is characterized by length of cut performed per unit time. Cutting includes also certain processes of formation of depressions on surface of metal (so-called surface cutting). Form of cross section, width and depth of surface cut (Fig. 66b) are determined by method of treatment, productivity of surface cutting — weight of metal removed per unit time.

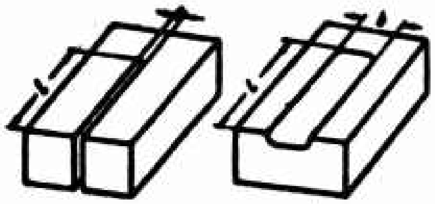


Fig. 66. Cuts: a) through; b) surface; l — length of cut; b — width.

Following design problems are solved with help of cutting:

1. Manufacture from sheet material of flat elements or components of constructions, having rectilinear, circular or irregular outlines with given accuracy and cleanliness.

2. Formation of openings and holes of different configuration with given accuracy and cleanliness in metal elements or components.

3. Shearing of bands, rods, pipes and sections of rolled stock into sections of measured length with given accuracy and cleanliness.

4. Treatment of edges of stamped, sheet and rolled elements, including different forms of their preparation for welding.

5. Cutting of metal blanks for subsequent treatment by pressure or removal of shavings.

6. Preparation of metal blanks and elements for subsequent welding and treatment by pressure.

Along with mechanical cutting there are in wide use methods of oxygen and electrical cutting, performed with the help of local, concentrated heating.

Methods of Cutting

Oxygen cutting (Fig. 67a) is based on ability of metals to burn in oxygen (cleanliness 99.5% and not below 98%) with liberation of a large quantity of heat. Burning occurs on surface of contact with oxygen stream preliminarily heated to temperature of ignition of metal (for low-carbon steels practically at about 1300°). Usually, use is made of accompanying heating of surface by flame of oxygen mixtures of gaseous or combustible vapors (acetylene, kerosene and others). Oxygen cutters have a device for mixing and burning of fuel and oxygen, for the formation of a stream of cutting oxygen, and for the control of feed of gases.

During through cutting, cutting stream should be narrow, long, and directed perpendicularly to surface being cut (during high-speed, rectilinear cutting, stream should be directed at an angle toward

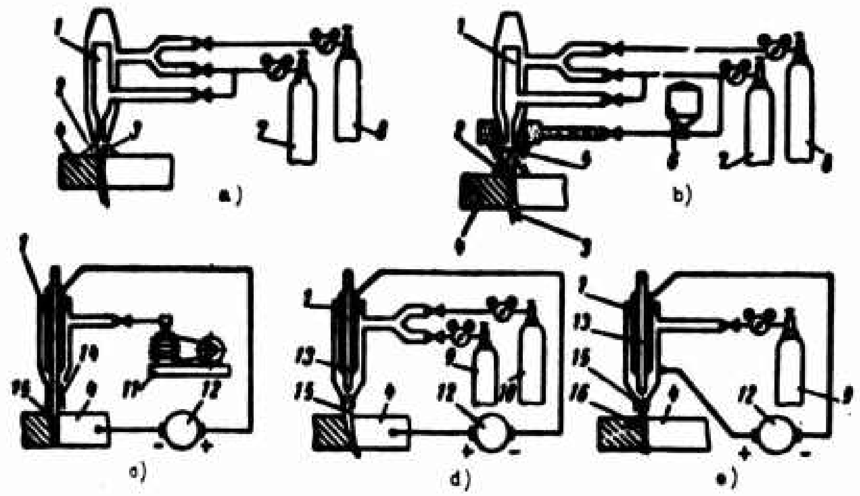


Fig. 67. Fundamental diagram of cutting: a) flame-oxygen; b) flux-oxygen; c) air-arc; d) penetrating arc; e) stream of plasma. On diagrams: 1 — cutter; 2 — heating flame; 3 — oxygen cutting stream; 4 — cut metal; 5 — flux carrying flow; 6 — flux feeder; 7 — cylinder with oxygen; 8 — cylinder with combustible gas; 9 — cylinder with neutral gas; 10 — cylinder with hydrogen; 11 — compressor; 12 — source of working current; 13 — electrode; 14 — flow of air; 15 — arc; 16 — stream of plasma.

side of movement of cutter). During surface cutting, stream should be wide, soft, and directed at an angle of 20-30° to the surface.

Oxygen can be used to cut steel with a low content of alloy elements (Table 91), and also titanium.

Table 91. Influence of Alloy Elements in Steel on Cutting

Degree of influence	Content of elements, in %, not less than				
	C	Cr	Al	W	Mo
Hampers . . .	0,3	3	2	10	0,25
Prevents . .	0,8	6	10	20	—

<u>Flux-oxygen cutting</u> (Fig. 67b) is characterized by feeding into stream of cutting oxygen fluxes with base of PZH iron powders (GOST 9849-61), during combustion of which, additional heat separates. This allows to cut cast iron, chrome-nickel steel and other metals, the combustion of which is hampered in stream of oxygen.

For cutting of heat-resistant alloys, one adds to the aluminum,

silicon and ferroalloys or uses as a flux a mixture of magnesium or aluminum-magnesium powder with siliconcalcium or ferrosilicon.

Air-arc cutting (Fig. 67c) consists of smelting of metal by an electrical arc and its removal with a stream of air, oriented along the electrode. Surface treatment of carbon and alloy steels is preferable; it is somewhat more difficult to process cast iron and nonferrous metals. Through cutting of alloy steels is possible.

In air-arc cutting, coal or graphite electrodes are used; copper-plated are better. The most efficient cutting arc uses direct current. During treatment of carbon and alloy steels, polarity is reverse ("plus" on electrode), nonferrous metals are cut by arc of straight polarity with maximum current, voltage and air pressure. Normally, working current is of 400-700 amp, voltage 35-40 v. Air pressure is 4-7 kg/cm^2, average consumption — 20 m^3/hr. Cast iron is more advantageous to cut by arc of alternating current with low air pressure (about 2 kg/cm^2). During surface cutting, diameter of electrode is selected 1-2 mm less than given width of groove (usually 6-12 mm). During through cutting, one uses electrodes of 8-10 mm diameter. In view of great width of cut and low productivity, through cutting of carbon steel, as a rule, is not recommended.

Cutting with a penetrating plasma arc (Fig. 67d) consists of smelting metal with an arc discharge, directed by a stream of gas, which assumes in head of cutter the properties of the plasma. Plasma flow removes smelted metal, prevents deflection of arc in sides and allows it to be extended during deepening in metal.

During cutting of aluminum, one uses argon, but for alloy steels — nitrogen. For more favorable heat transfer, one adds up to 35-50% hydrogen. Copper of great thickness is better cut in pure

hydrogen. Consumption of gas normally constitutes 2-2.5 m^3/hr for a pressure of 0.2-0.3 kg/cm^2. For cutting, air and steam are also used.

The most effective is the penetrating arc of direct current (straight polarity). Magnitude of current (250-400 amp) affects speed of cutting and width of cut. Voltage of arc (50-100 v and above) depends on diameter of nozzle, composition and consumption of gas and grows with thickness of cut metal. Limiting cut thickness of metal is determined by idling voltage and volt-ampere characteristic of source of current. Penetrating arc can be used to cut any metals, including aluminum and magnesium alloys, and also rust-resistant and heat-resistant steels with a thickness over 100 mm copper and its alloys with a thickness up to 80-100 mm.

Plasma cutting (Fig. 67e) is carried out by smelting of material with a stream of high-temperature gas plasma, separated from arc discharge, burning in submouthpiece space of plasma generator. Stream possesses great kinetic energy and intensively removes products of smelting from cut. Not being electrically connected with object of treatment, plasma stream may be applied for cutting of electrically nonconducting materials. Usually one uses plasma of argon, nitrogen or mixture of these gases. Process is powerwise efficient for significant (3-5 m^3/hr) consumption, moderate (300-400 amp) currents, and high (50-60 v) voltage. For feeding of arc, as a rule, one uses direct current of straight polarity.

Maximum thickness of material cut by plasma depends on capacity of plasma generating arc, composition and consumption of gas, form of nozzle and speed of cutting. One can cut, for instance, stainless steel with a thickness of 40-50 mm. With increase of thickness of

Table 92. Fields of Application of Oxygen and Electrical Cutting

Type of treatment	Processed metals	Thickness of material, in mm or characteristic of sections of cutting	Cutting	Standard equipment
Laying-out of sheets, cutting of flat-shaped components and blanks of pipes, reinforcement, rolled stock, forgings, castings, cutting of openings and holes, preparation of edges for joining by welding	Carbon and low-alloy steel and titanium	4-800 and above	Flame-oxygen	Universal acetylene-oxygen cutter "Plamya" (5-300 mm) Acetylene-oxygen cutter RR-600 for large thicknesses (300-700 mm) Acetylene-oxygen cutter R-100, low pressure for large thicknesses (300-2000 mm) Cutting mechanisms
	Alloy steel, nonferrous metals, cast iron	Up to 4-5 (including nonmetallic materials)	Plasma	Head IMET-106a, Cutter GPN-1-60 Cutting mechanisms
		4-200	Penetrating arc	Cutter, small, RDM-1-60 (4-30 mm) Unit UDR-2M (4-100 mm) Unit UPR-1 (over 100 mm) Cutting mechanisms
		5-25	Air-arc	Cutter RVD-1-59
		20-500	Flux-oxygen	Equipment URKhS-4 for standard cutters (10-100 mm) Unit UFR-2 Cutting mechanisms
Selection of grooves, stripping of surfaces of blanks, dressing of defects of casting, forgings and welded seams	Carbon and low-alloy steels	Drawn, wide sections	Flame-oxygen	Cutter RPA-50
		Narrow sections of small length (including curvilinear)	Air-arc	Cutter RVD-1-59
	Alloy steels, nonferrous metals, cast iron	Drawn, wide sections	Flux-oxygen	Unit URKhS-3 with cutter RPKF-3
		Narrow sections of small length	Air-arc	Cutter RVD-1-59
		Deep earthen and slag cavities, looseness, impurities	Arc	Electrode holder
Underwater cutting	Carbon and stainless steels, cast iron, nonferrous metals	5-100	Oxygen-arc	Oxygen-arc cutter

cut material, speed of cutting strongly drops. Plasma can be used efficiently for cutting of nonferrous metals and alloy steels of small (up to 4-5 mm) thickness and nonmetallic materials.

Arc and oxygen-arc cutting have limited application. First is used for coarse cutting of cast iron, alloy steels and nonferrous metals, for small volumes of cutting in electric welding work and treating of metal to manageable scrap for charge. Oxygen-arc method finds application mainly in underwater work, where it is an irreplaceable means of effective cutting of pack elements of welded constructions.

Fields of application of different methods of cutting are shown in Table 92. In Fig. 68, 69, 70 are shown their technical specifications.

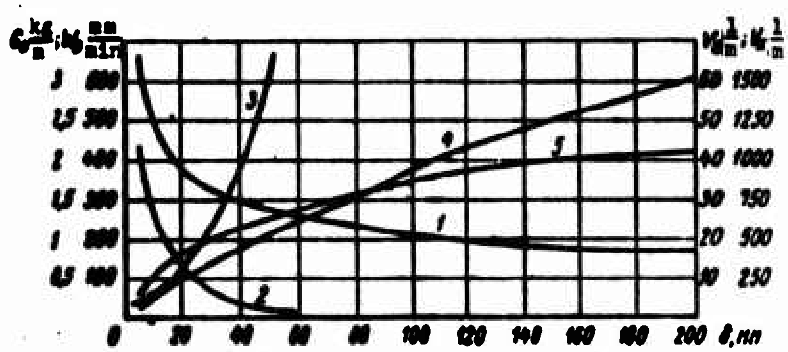


Fig. 68. Characteristics of cutting of carbon steel: W_p – speed: 1 – flame-oxygen cutting (class II, steel with clean surface); 2 – speed of arc cutting with steel electrodes 5 mm in diameter, current 400 amp; 3 – consumption of electrode G_3; 4 – consumption of oxygen V_K; 5 – consumption of acetylene V_a; δ – thickness of steel.

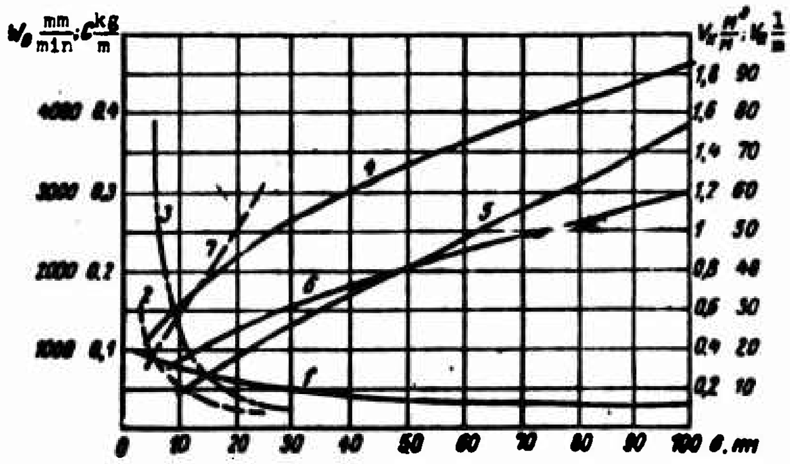


Fig. 69. Characteristics of cutting of stainless steel: W_p – speed: 1 – flux-oxygen cutting (unit URKhS-4); 2 – air-arc cutting; 3 – cutting with penetrating arc in nitrogen and its mixture with hydrogen; 4 – consumption of flux G; 5 – consumption of oxygen V_K; 6 – consumption of acetylene V_a; 7 – consumption of electrodes G; δ – thickness of steel.

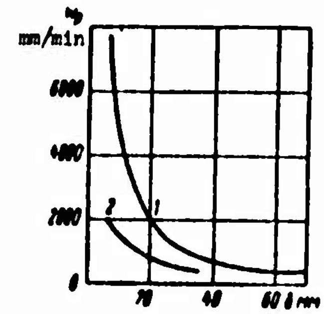


Fig. 70. Dependence of speed of cutting W_p by penetrating arc in argon-hydrogen mixture of sheet aluminum an its thickness δ: 1 – mechanized cutting 2 – manual cutting.

Equipment

For cutting, the following are necessary: cutter, source of energy (cylinders with gases, welding generator, compressor etc.) and auxiliary devices (gas reducers, measuring instruments and others). Cutting mechanisms (GOST 5614-58) in use are as follows: specialized, narrow-purpose and universal – for cutting flat components of arbitrary contour (Table 93), and also attachments for manual cutting (compasses, patterns, carts and so forth).

Table 93. Characteristic of Machines for Cutting

Type and name of machine	Purpose	System in accordance with GOST 5614-58	Method of copying	Dimensions of processed sheet (length × × width, in m)
SGU	Stationary, universal, for cutting of sheet metal with oxygen or penetrating arc	Right-angle-coordinate	Magnetic copying or photocopying	6 × 2
"Odessa"	Stationary, universal, for oxygen cutting of sheet steel	The same	Scale magnetic or photocopying	9 × 3
MDM-3	The same	The same	Program contron from magnetic tape or scale photocopying	10 × 2.5
MDFKS	The same	The same	Remote-scale photocopying	9.5 × 2
GSV	Mobile, universal, for oxygen cutting sheet steel	The same	Magnetic copying	1 × 1
ASSh-2	Stationary, universal, for precision oxygen cutting of sheet steel	Polar-coordinate	Magnetic copying	1 × 1 or 1.5 × 0.75
PR-3.5M	Stationary, gas cutting for right-angle cut of sheets and preparation of edges	Linear	–	16 × 3.5
Chernomor	The same	The same	–	16 × 3.5
UDR-1	Portable, for cutting sheet metal with penetrating arc	Machine-cart	–	Unlimited
PP-1	Portable, for oxygen cutting sheet steel with thickness of 5-250	The same	–	Unlimited
PP-2	Two-cutter, portable for oxygen cutting of sheet steel and preparation of edges, with thickness of 5-100 mm	Machine cart	–	–
PMR-600	Portable, for oxygen cutting, with thickness up to 600 mm	The same	–	Unlimited
TR-1	Portable, for oxygen cutting and bevel of edges of nonturning steel pipes	–	–	Diameter 150-300 mm
Kudryavtsev pipe cutter	Stationary, for shaped oxygen cutting of turning steel pipes	–	–	Diameter 108-529 mm

Quality of Cutting

Flame-oxygen cutting does not evoke overburning and overheating of edge of cut. Hot oxides of iron melt and wash off the layer of unoxidized metal. In process of cutting, edges of cut are enriched by impurities possessing a smaller affinity for oxygen than iron, and are impoverished by impurities with a large affinity for oxygen. Surface layer 2-4 mm in depth is subjected to normalizing or, in case of cutting of hardening steels, to hardening. High hardness is removed by general or local tempering. During cutting of hardened steels, there are possible cracks on the edge, which can be avoided by preliminary preheating of the steel to 100-200°C. Edges of the cut, as a rule, are suitable for welding without machining.

During flux-oxygen cutting of steels of austenitic class, on the edge of the cut an austenite-dendritic structure is observed after which follows a section of enlarged grains of austenite. Cracks do not form on edges. During cutting of high-chrome steels of semi-ferrite class, structure of metal on edge is characterized by gradual transition from troostite-matensite to troostite with ferrite. No noticeable strains appear on the surface of the cut.

Edges of cut are impoverished in alloy elements to a depth of 0.5 mm. If component, after cutting, is not subjected to high-temperature heating and significant deformations, it is expedient to produce roughing of surface of cut with an emery wheel to a depth of up to 0.25-0.5 mm.

After air-arc cutting of steel, surfaces of cut are free from oxides. Layer of fused metal during surface cutting is practically absent, during through cutting it has an insignificant thickness. A certain carburization of cut to a depth of up to 0.2 mm is possible.

Cutting with a penetrating arc and stream of arc plasma is accompanied by the appearance on the edges of unoxidized metal, fused to a depth of 0.1-0.3 mm. Edges after cutting usually are suitable for welding. During use of hydrogen-containing gas mixtures, gas inclusions can form in fused layer. In avoiding poreformation in welds of certain steels, alloy AMG, and others, grinding of edges to 0.2-0.4 mm is useful.

Metal on edges of a through arc or oxygen-arc cut, carried out with a tubular electrode, is noticeably oxidized, nonuniformly fused, and often contaminated with nonmetallic inclusions. After surface arc cutting with electrodes with a high-grade coating, it is possible to weld after stripping with a steel brush.

Quality of surface cut is characterized by degree of rounding of upper edge and linking of slag with lower edge, uniformity of width of cut along height, quantity and dimensions of local protrusions, depth and distortion of grooves (lag) on surface cut (Table 94).

Width of cut depends on method and conditions of cutting and thickness of metal (Table 95).

Mechanical accuracy of cutting is determined by accuracy of manufacture of templet and magnitude of error of copying, which depends on kinematic diagram of machine, quality of its manufacture and sometimes on place of distribution of cut component on sheet. For precision machines, error of copying usually is ±0.2 mm, for machines of average accuracy, it constitutes about ±0.5 mm.

Inaccuracy of passage of oxygen stream and burning of metal with a thickness up to 25 mm lies within li ts ±0.15 mm. Inaccuracy of cutting of sheets of large thickness is increased approximately by 0.1 mm for every 50 mm. Less exact is melting of metal by stream of

Table 94. Classification of Forms of Through Cutting

Characteristic	Class of quality and accuracy				
	I	II	III	IV	V
	Forms of cutting				
	Finish cutting of shaped components without subsequent treatment	Finish cutting of rectilinear edges without subsequent treatment	Cutting of rectilinear components not requiring high accuracy	Cutting of shaped components with allowance for treatment of contour	Preparatory cutting
Coefficient of lag......	0.06-0.15	0.3-0.5	0.6-0.8	1.0	1.5-2.0
Depth of grooves, in mm	0.1	0.3	Is not regulated		
Radius of rounding of upper edge, in mm.....	0.2	0.5	1.0	Within limits of allowance	The same
Depth of protrusions, in mm..................	Are allowed, as an exception, with subsequent welding and stripping	1.0	2	2.5	4
Length of snatching, in mm..................		2.5	5	8	10
Number of protrusions per running m.........		2	3	4	5
Deflection of dimensions from face value in mm (for length up to 1 m and thickness of 5 mm)	±(0.2-0.25)	±(0.3-0.5)	0.8	1.0	1.0
Deflection from rectilinearity, in mm/m....	—	0.15-0.2	0.25	—	Is not regulated
Deflection of height of blunting of edge, in mm..................	—	±0.5	±1-0.5	—	—
Deflection of angle of bevel of edge, in degrees..............	—	±2.0	±3	—	—

Table 95. Tentative Width of Cut, in mm

Method of cutting	Thickness of metal, in mm			
	5-25	25-50	50-100	100-300
Flame-oxygen..................	2.5-4	3-5	4-6	5-10
Flux-oxygen..................	4-8	6-12	8-15	10-25
Arc..........................	6-9	8-12	10-18	—
Air-arc......................	8-15	—	—	—
Plasma-arc...................	4-8	8-12	12-16	—
Plasma.......................	1-3	3-5	—	—

plasma and penetrating arc. Stream error of gas-arc cutting usually constitutes about ±1 mm. Besides, there is also observed nonparallelism of lateral surfaces of cut. Inaccuracy of cutting due to thermal deformation of sheet is remove by fastening it on one of the edges; moreover, cutter is shifted in the direction of fastening. Smallest deformations appear during cutting of components from wider sheets. In addition, components cut first have smaller measured deflections and deformations. The biggest accuracy is obtained during cutting simultaneously with two cutters located in one frontal plane.

Comparison of Cutting with Other Forms of Treatment

Cutting of metals allows to execute operation that are difficult to accomplish in other ways: manufacture of flat, large-dimension components with complicated contour, separation of metallic elements of great thickness, treatment of metals possessing high hardness, shaped cutting of nonturning pipes, cutting during assembly and so forth.

Oxygen cutting of steel sheets with thickness of 10-20 mm is 1.5-2 times and cutting of aluminum and stainless steel by penetrating arc is 2.5 times more economical than machining. Oxygen cutting reduces 2-3 times cost of treatment of edges in welding.

Table 96. Economy and Labor-Consumption of Different Methods of Surface Treatment of Metals

Method of treatment	Carbon steels		Austenitic steels		Hard alloys		Nonferrous metals	
	Time	Value	Time	Value	Time	Value	Time	Value
Chopping with pneumatic chisel........	1	1	1.5	1.5	–	–	0.5-1	0.5-1
Grinding with corundum wheel..........	0.8	1.3	0.9	1.8	1.5	2	1	1
Milling..............................	0.4	0.4	0.6	0.8	–	–	0.3	0.3
Flame-oxygen planning................	0.15	0.2	–	–	–	–	–	–
Air-arc cutting......................	0.1	0.3	0.1	0.3	0.1	0.3	1	0.8

Note: Expenditure of time and cost in chopping carbon steel with pneumatic chisel have been taken as unity.

One-sided (V-shaped treatment) and bilateral bevels (X-shaped treatment) of rectilinear, slightly curved or circular edges are performed on gas-cutting mechanisms equipped, respectively, with two or three cutters. Other methods are most accessible to perform one-sided bevel without blunting (with one cutter).

For production of slanting cuts of components with curvilinear contours, mechanisms equipped with a special device are necessary.

Expediency of application of cutting is determined also by magnitude of metal waste. For instance, large disks and right-angle blanks of small thickness (10-20 mm) are more expediently cut from sheets. Disks of small diameter and large thickness are more rational to saw from round stock. Cost of cutting, especially on photocopying machines, practically does not depend on magnitude of prepared lot, while cost of manufacture of components by stamping strongly depends on it. Small lots of components (up to several hundred pieces) are more economical

to prepare by cutting; big lots — by stamping.

Surface cutting of steels and components covered by hard alloys is more productive and more economical than pneumatic treatment, grinding and milling (Table 96).

SOLDERING OF METALS

Basic Ideas

Soldering is called the technological process of joining components in a heated state with the help of a comparatively fusible alloy (solder), which during period of melting melts well the surface of the soldered components, and during period of crystallization connects them.

Soldering is successfully applied in manufacture of such critical articles, as hollow blades of propellers of aircraft, cooling blades of gas turbines, heat exchangers for atomic reactors and others.

For protection of surface of combinable components from oxidation in process of soldering fluxes are used or components are heated for protective or reducing atmosphere, and also in vacuum.

As solder, one usually uses clean metals or alloys, which are well alloyed with material of components and, in comparison with it, are more easily fusible.

Solders are conditionally divided into two groups: hard — refractory and highly durable; soft — fusible, possessing significantly smaller durability.

In accordance with names of solders, metals are also conditionally divided into hard and soft.

Soft soldering is applied when article is not required to have high strength, but airtightness or electrical conductivity of soldered joint are chiefly required.

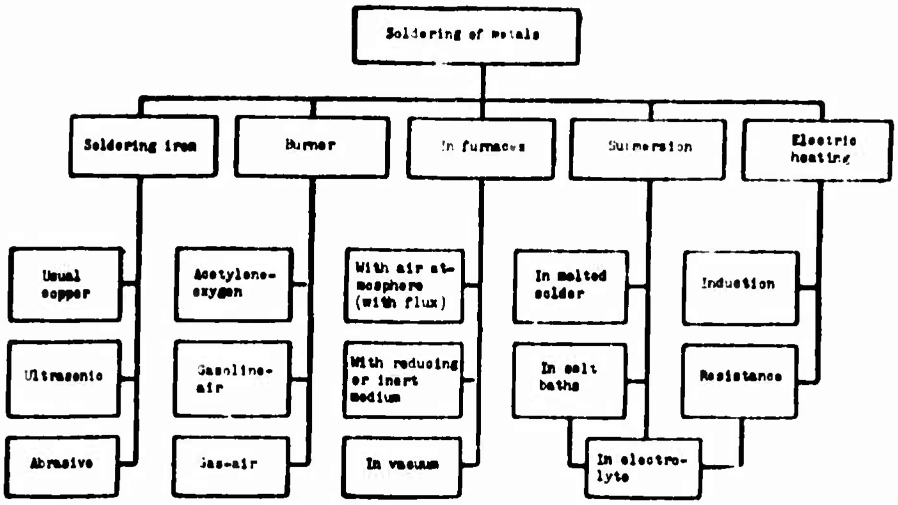


Fig. 71. Classification of basic forms of soldering by method of heating.

Hard soldering ensures high-quality joints, which in strength are close to welded seams.

Processes of soldering can expediently be classified by methods of heating (Fig. 71).

Forms of Soldering

Soldering by soldering iron. The most wide-spread is soldering with a usual (copper) soldering iron. Besides that, ultrasonic and abrasive soldering irons are used.

Heating with usual (copper) soldering iron is used during soldering of metals with easily fusible solders of tin-lead base or other solders with fusion temperature not higher than 300°. For removal of oxidized film, fluxes are used. One distinguishes soldering irons as of periodic and continuous action. Electrical soldering irons of continuous action ensure high quality of seams and promote increase of productivity of labor during soldering.

Soldering by ultrasonic soldering irons is without flux; oxidized film is destroyed from ultrasonic oscillations of soldering iron.

This method is finding application for soldering of aluminum components with fusible solders.

Abrasive soldering iron is used during soldering of aluminum with fusible solders without a flux. Oxide film is removed from surface of aluminum in process of soldering by mechanical means under layer of molten solder by friction of abrasive pressed in the rod of soldering iron. In separate cases, one uses rods pressed from a mixture of solder and abrasive material. During abrasive soldering, additional heating of combinable details is required.

Soldering with a burner is applied more frequently during use of refractory solders. Depending upon complexity and quantity of prepared components, soldering may be manual, mechanized or automatic. For high-temperature soldering of steels and also copper and nickel alloys, an acetylene-oxygen burner is used, but for soldering of aluminum and magnesium alloys, gasoline or gas-air burners are preferred.

During soldering of large-size articles, one should not apply local heating by burner, since it evokes significant deformation of article.

Furnace soldering ensures uniform heating of metal, which allows to use successfully this method of manufacture of large-size, thin-walled articles without their noticeable warping, and also during mass production of small components. With help of soldering in furnace it is possible to prepare complicated critical assemblies from a large quantity of components (Fig. 72a and b).

During soldering in furnaces with an air atmosphere, for removal of oxidized film and protection of metal from oxidation, fluxes are used. The most wide-spread are furnaces with a reducing or inert

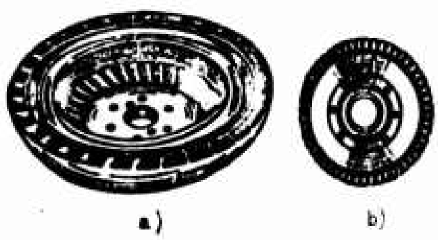


Fig. 72. Assemblies prepared with the help of soldering in furnace: a) entrance apparatus of compressor soldered from 80 components; b) rotor of turbine.

atmosphere, and also vacuum furnaces which allow soldering without application of flux. During mass production, one should apply electrical belt-conveyer furnaces with a reducing atmosphere, which ensure high productivity of labor.

Soldering by submersion in melted solder with use of flux is used when it is necessary simultaneously to connect a large quantity of components in to one assembly, for instance, tubular radiators, collectors of an electric motor, etc. With this method of soldering one uses chiefly fusible solders.

Soldering in salt baths is possible by means of refractory and fusible solders. Melted salt serves in this case simultaneously as a flux and heat source.

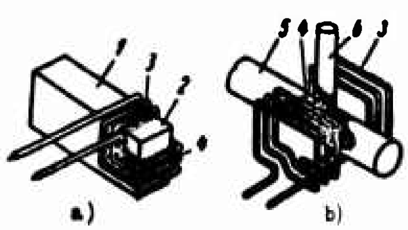


Fig. 73. Diagram of high-frequency soldering: a) soldering of hard-alloy tool; b) soldering of tee: 1 — commercial cutter; 2 — hard alloy plate; 3 — inductor; 4 — zone of heating of metal; 5 and 6) combinable pipes.

During direct electric heating, as distinct from other methods, the necessary heat appears in the components themselves as a result of the influence of an alternating magnetic field of high frequency (induction soldering, Fig. 73), or by passage of electrical current through combinable surfaces.

In recent years, heating of components during soldering in electrolyte (for instance, in water solution of soda) is beginning to come into use. With this method, just as during soldering in salt baths, solder on combinable details is applied prior to soldering in the form of foil or wire.

During soldering in electrolyte, in process of heating, hydrogen separates on components (on cathode), which reduces oxides on combinable surfaces and ensures nonoxidizing heating during soldering.

Indicated forms of electric heating of components during soldering are high-speed and make it possible to mechanize and to automate process of soldering.

Selection of heating method during soldering depends on temperature of fusion of solder, material and dimensions of article and technical requirements inposed on it.

Designing Soldered Joints

A correctly designed joint should be convenient in assembly before soldering, but after soldering it should work reliably under influence of operating loads.

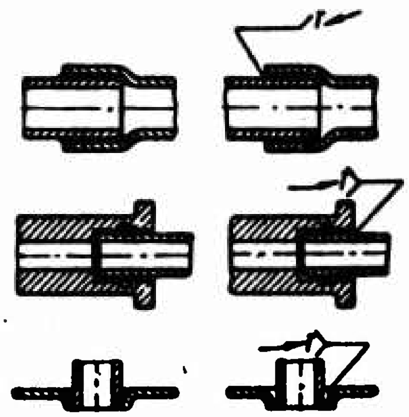


Fig. 74. Examples of application of designations on drawings. On the right is shown drawing of joint prior to soldering, on the left — desirable form of joint after soldering. Instructions on technology of soldering process should be placed in spot shown by letter T.

So that technologists could more exactly accomplish the idea of the designers, it is expedient to make additional sketches and instructions on drawings (Fig. 74), defining configuration of soldered joint method of application of solder, preparation of components for soldering etc.

During selection of basic material, it is necessary to consider of its property not only in state of delivery, but also after heating of material in process of soldering.

During selection of solder, one considers mainly operating requirements for

properties of soldered joint (strength, corrosion stability, electrical conductivity etc.).

Temperature of fusion of solder should be lower than temperature of fusion of combinable metals by not less than 50-100°, but higher than operating temperature of soldered articles.

Melted solder should wet well the combinable metals and flow in gaps between components.

If it is necessary to have consecutive (stepwise) soldering of several closely located joints, one selects solders with different temperatures of fusion and uses them consecutively, starting with the most refractory one.

During joining of heterogeneous materials, it is very important to consider difference in coefficients of their thermal expansion, which can lead to appearance of significant thermal straines and even to destruction of soldered joints in process of soldering or after it.

In selecting type of joint for soldering, it is necessary to remember that solder, in comparison with basic metal, as a rule, is less strong and, therefore, area of soldered joint should be significantly larger than area of cross section of the thinnest of combinable components. Considering this, during soldering one rarely uses butt joints and uses widely overlapping joints.

Magnitude of overlap, corresponding to conditions of equal-strength of soldered seam of components in place of soldering, can be determined by the formula

$$l = \frac{\sigma_b \delta}{\tau_{cp}},$$

where l — length of overlap in mm; σ_b — shear strength of less strong

of the combinable components in kg/mm^2; δ — thickness of less strong component in mm; τ_{cp} — ultimate strength of soldered seam in cut, in kg/mm^2.

Practically, during soldering with refractory (high-strength) solders, equal strength of joint is ensured, if length of overlap exceeds 3 times and more thickness of the thinnest part of soldered joint.

Basic types of joints are shown in Fig. 75. In Fig. 76 are depicted examples of unsuccessfully designed soldered joints, applicable to standard loads, shown by pointers.

Large influence on strength of soldered joint is exerted magnitude of connecting gap, which determines thickness of layer of solder in soldered seam and, in a significant measure, determines strength of soldered joint. Thus, for instance, for large gaps, and during brief heating when soldering, strength of soldered joint is approximately equal to strength of applied solder. For small gaps and comparatively prolonged heating, when soldering, composition of solder changes sharply through diffusion and strength of joint is already determined by strength of that new alloy which was formed in narrow gap in process of soldering. In a majority of cases, for instance during soldering of steel and copper, strength of the joint is greater, the less the connecting gap and the more the holding time of articles at temperature of soldering. However, too small gaps require high accuracy of manufacture of components and do not always ensure inflow of molten solder. Therefore, in designing soldered joints, it is necessary to select optimum dimensions of gaps, which, for a majority of solders, lie within limits of 0.05-0.15 mm.

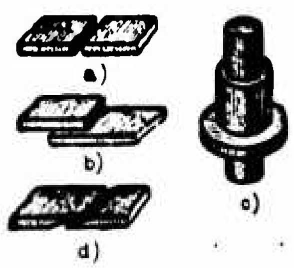


Fig. 75. Basic types of soldered joints: a) butt; b) overlap; c) bushing joint; d) oblique butt.

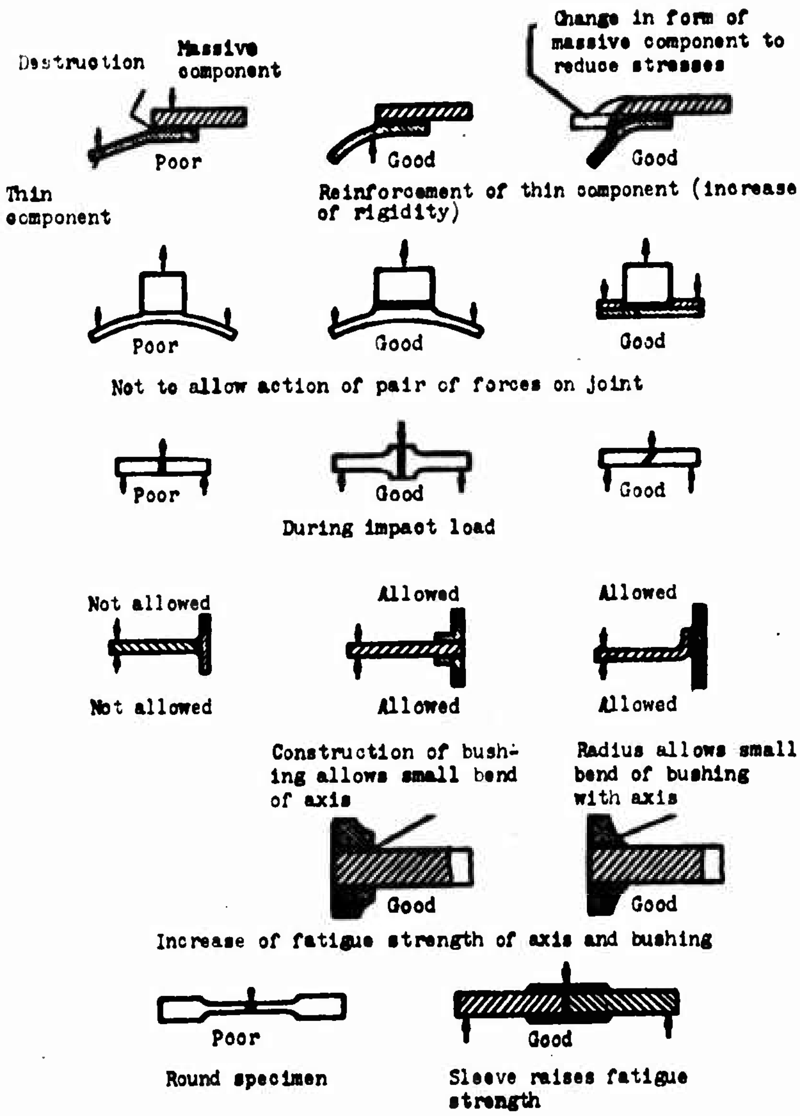
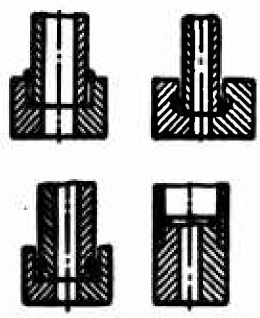


Fig. 76. Examples correctly and incorrectly designed soldered joints.

Fig. 77. Methods of distribution of solder in the form of wire during soldering of mechanically treated details.



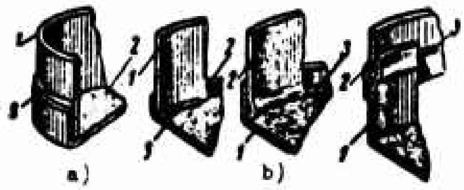


Fig. 78. Laying of solder in places of joining of components stamped from sheet material: a) solder in the form of foil; b) solder in the form of wire: 1 and 2 – combinable components 3 – solder.

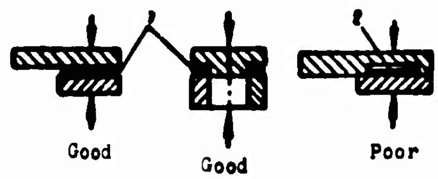


Fig. 79. Distribution of solder in the form of washers: 1 – lining or washer; 2 – lining.

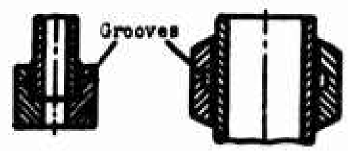


Fig. 80. Soldered joints with grooves for laying the solder.

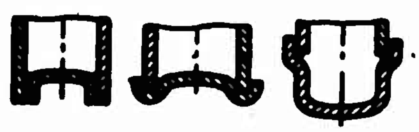


Fig. 81. Standard soldered joints of hermetic containers.

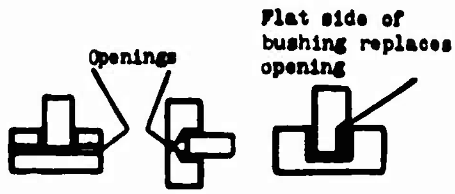


Fig. 82. Ventilation of blind soldered joints during soldering.

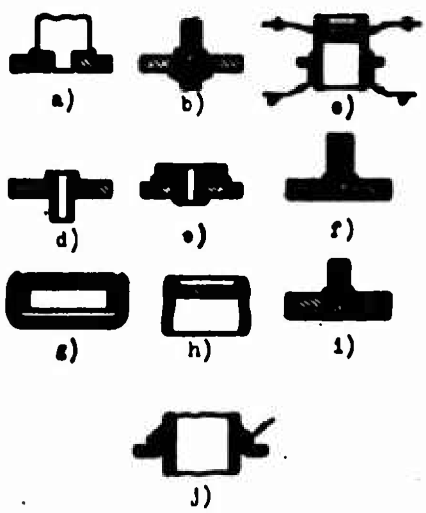


Fig. 83. Examples of assembly of components in soldering without auxiliary attachments, with use of: a) gravity; b) skirting; c) spot welding; d) expansion; e) upsetting; f) light pressing; g) calking; h) corrugations; i) gravity (ventilated seam); j) pin.

In designing soldered joints, it is necessary to pay special attention to selection of form of solder (wire, foil) and to convenience of its distribution during assembly of joints when soldering (Figs. 77-80).

In designing hermetic, soldered containers and other vessels intended for work pressure or in vacuum, one should apply joints of the overlapping type (Fig. 81). It is very important, besides, to provide a technological (temporary) hole for exit from vessel of gases which expand from the heat in process of soldering. Otherwise, expanded gas will break through melted solder and disturb airtightness of soldered seam. It is necessary also to provide ventilation channels in (blind) soldered joints (Fig. 82).

Designer, jointly with manufacturing engineer, should consider problem of methods of cleaning components before assembly and select method of assembly of components in soldering, taking into account the most wide-spread (simplest) methods of fixation of components (Fig. 83), allowing easily to carry out process of soldering without application of complicated and expensive attachments.

By observance of above-indicated requirements one can obtain soldered joints, which in strength and reliability will, in a number of cases, be equivalent to welded joints.

Table 97. Tin-Lead Solders [48], [49]

Brand of solder	GOST	Chemical composition						temperature in °C		σ_B in kg/mm^2	δ in %	γ in g/cm^2	ρ in ohm·mm^2/m	Typical use
		Sn	Sb	Ag	Zn	Cd	Pb	start of fusion	full melting					
POS 90	1499-54	89-90	Not over 0.15	—	—	—	Remaining	183	222	4.3	25	7.6	0.143	Internal seams of food dishes and medical equipment
POS 61	1499-54	59-61	Not over 0.8	—	—	—	The same	183	183	4.1	34	8.3	0.155	Critical components in electrical engineering and instrument making when components must not be heated higher than 200°
POS 50	1499-54	49-50	Not over 0.8	—	—	—	The same	183	209	3.6	32	8.8	—	Critical components
POS 40	1499-54	39-40	1.5-2.0	—	—	—	The same	183	235	5.6	50	9.3	0.171	Soldering of copper, brass, steels, galvanized iron, electrical-radio equipment, and also during installation of electrical work
POS 30	1499-54	29-30	1.5-2.0	—	—	—	The same	183	256	4.9	32	9.7	0.160	
POS 18	1499-54	17-18	2.0-2.5	—	—	—	The same	183	277	2.8	67	10.2	—	The same, but less technological than preceding solders
POSS 4-6	1499-54	3-4	5-6	—	—	—	The same	245	265	5.8	14	10.7	—	Noncritical components, since seams possess insufficient ductility
PSr 3	8190-56	—	—	3.0 ± ± 0.3	—	—	97.0 ± ± 1.0	300	305	3.1	45	11.3	0.200	Copper and brass components operating at a temperature up to 150°C
PSr 2.5	8190-56	5.5 ± ± 0.5	—	2.5 ± ± 0.3	—	—	92.0 ± ± 1.0	295	305	3.6	—	11.0	0.220	The same, but is more technological
PSrZKd	8190-56	—	—	3.0 ± ± 0.5	1.0 ± ± 0.5	96.0 ± ± 1.0	—	300	325	13.5	—	8.7	0.078	Soldering of copper conductors to collector of generator; heat-resistant solder (up to 170°)

<u>Notes</u>: 1. Solders POS 61 and POS 50 possess improved technological properties, give tighter seams, but do not have substantial advantages over solder POS 40 with respect to strength.

2. Solder PSrZKd with a cadmium base is introduced in table as a heat-resistant solder for comparison with solders PSr 3 and PSr 2.5.

Table 98. Mechanical Properties of Solders POS 40, POS 30 and POS 18 at Normal and Low Temperatures [50]

Brand of solder	Temperature of test, in °C	Ultimate strength on extension, in kg/mm^2	Elongation ratio, in %	Shear strength in kg/mm^2
POS 40	+20	5.6	50	3.9
	-30	9.5	22	—
	-50	—	—	6.4
	-60	11.8	16	—
	-96	12.6	14	8.0
	-183	13.4	3	9.6
	-196	13.4	2	10.0
POS 30	+20	4.9	32	3.5
	-30	7.8	22	—
	-50	—	—	5.8
	-60	7.9	16	—
	-96	10.3	10	6.9
	-183	11.6	4	9.0
	-196	12.0	2	9.1
POS 18	+85	2.8	23	—
	+20	4.2	10	3.6
	-30	6.5	6	—
	-50	—	—	5.3
	-60	6.5	5	—
	-96	7.4	4	6.6
	-183	10.1	3	8.0
	-196	11.1	2	8.2

Table 99. Strength of Soldered Joints at Normal, High and Low Temperatures, in kg/mm (Soldering by Overlapping) [50]

Brand of solder	Basic metal	Temperature of test, in °C					
		−196	−183	−96	−60	+20	+85
POS 40	Copper M3	3.5	3.2	3.4	3.5	2.7	1.6
	Brass L62	2.9	2.9	5.1	3.7	3.2	[illegible]
	Steel 20	6.0	6.5	5.5	5.1	3.8	[illegible]
	Steel 1Kh18N9T	3.8	3.4	3.8	5.0	3.3	[illegible]
POS 30	Copper M3	3.1	3.7	3.8	3.3	3.5	1.5
	Brass L62	3.2	3.5	3.7	3.0	3.3	1.4
	Steel 20	6.3	5.6	5.8	5.9	3.6	2.8
	Steel 1Kh18N9T	4.2	3.8	3.6	4.5	3.2	1.8
POS 18	Copper M3	3.3	3.8	2.7	3.0	2.0	1.7
	Brass L62	2.9	2.7	2.5	2.9	1.8	1.4
	Steel 20	7.1	7.2	4.3	3.9	3.2	1.7
	Steel 1Kh18N9T	4.6	5.1	4.8	4.9	2.6	1.1

Table 100. Prolonged Strength of Soldered Joints at Normal Temperature [50]

Solder	Metal of specimen	Stress, in kg/mm²	Time prior to destruction in hrs	Solder	Metal of specimen	Stress, in kg/mm²	Time prior to destruction in hrs
POS 40	Copper M3	1.06 0.61 0.46 0.33 0.31 0.30	6 24 260 384 1440 Above 8000	POS 30	Brass L62	1.57 0.58 0.36 0.35 0.24 0.16	8 876 1056 1876 2476 Above 7500
	Brass L62	1.06 0.56 0.29 0.23	6 113 2380 Above 7800	POS 18	Copper M3	0.84 0.54 0.37 0.33	130 1440 3164 Above 8000
	Steel St. 3	0.94 0.33 0.28 0.26	86 1485 2264 Above 8000		Brass L62	1.00 0.57 0.50 0.32 0.27 0.24	38 792 2116 3316 8000 8600

Table 101. Silver Solders (GOST 8189-56)

Brand of solder	Chemical composition, in %								γ in g/cm³	ρ in ohm·mm²/m	Soldered metals
	Ag	Cu	Zn	Cd	Ni	Others	Begin-ning of fusion	Full melt-ing			
PSr 72	72.0 ± 0.5	$28.0^{+0.5}_{-0.7}$	–	–	–	–	779	779	9.9	0.022	Copper wires and components of instruments, when place of joint should possess high electrical conductivity and also vacuum instruments and units
PSr 50	50.0 ± 0.5	$50.0^{+0.5}_{-0.7}$	–	–	–	–	779	850	9.3	0.025	The same, but soldering at higher temperatures
PSr 70	70.0 ± 0.5	26.0 ± 0.5	4.0 ± 1.0	–	–	–	730	755	9.8	0.042	Copper, brass and steels. Seams are less electroconducting than during soldering with PSr 72
PSr 65	65.0 ± 0.5	20.0 ± 0.5	$15.0^{+1.0}_{-1.5}$	–	–	–	740	–	9.6	0.090	Steel, copper, nickel and their alloys. Soldered seams possess comparatively high strength and high strength and have silvery color
PSr 45	45.0 ± 0.5	30.0 ± 0.5	$25.0^{+1.0}_{-1.5}$	–	–	–	660	725	9.1	0.097	Steel, copper, nickel and their alloys. Solder of general use
PSr 25	25.0 ± 0.3	40.0 ± 1.0	$35.0^{+1.5}_{-2.0}$	–	–	–	745	775	8.7	0.069	The same
PSr 12M	12.0 ± 0.3	52.0 ± 1.0	$36.0^{+1.5}_{-2.0}$	–	–	–	780	825	8.5	0.076	Steels, copper, bronze and brass. Possesses lowered technological properties
PSr 10	10.0 ± 0.3	53.0 ± 1.0	$37.0^{+1.5}_{-2.0}$	–	–	–	815	850	8.4	0.065	The same
PSr 71	71.0 ± 0.5	$28.0^{+0.7}_{-1.0}$	–	–	–	P 1.0 ± 0.2	750	795	9.8	0.040	Copper and its alloys
PSr 25F	25.0 ± 0.5	70.0 ± 1.0	–	–	–	P 5.0 ± 0.5	650	710	8.5	0.180	Copper and bronze
PSr 15	15.0 ± 0.5	80.2 ± 1.0	–	–	–	P $4.8^{+0.2}_{-0.3}$	635	810	8.3	0.220	
PSr 50Kd	50.0 ± 0.5	16.0 ± 1.0	16.0 ± 1.0	18.0 ± ± 1.0	–	–	635	650	9.3	0.072	Honey, brass, bronze, steel, and also alloys of iron and nickel. Solder of general use
PSr 40	40.0 ± 1.0	$16.7^{+0.7}_{-0.3}$	$17.0^{+0.8}_{-0.4}$	$26.0^{+0.5}_{-1.0}$	0.3 + + 0.2	–	595	605	8.4	0.072	Components from hardened construction and stainless steels, and also from copper and nickel alloys, when one cannot heat them to high temperatures, but soldered joint must have high strength. Soldered joints have high corrosion stability
PSr 25KN*	25.0 ± 0.6	35.0 ± 0.6	–	15.0 ± ± 0.7	0.3 ± ± 0.2	–	690	740	8.9	0.077	Steel, copper and nickel alloys. Solder is substitute of PSR 45. More corrosion resistant under atmospheric conditions
PSr 37.5	37.5 ± 0.5	48.8 ± ± 1.0	5.5 ± ± 0.5	–	–	Mn 8.2 ± 0.3	725	810	8.9	0.310	Steel and copper components working at high temperatures. At 600° strength of soldered joints is 20% higher than in soldering with PSr 45 and PSr 25.

*Nonstandard.

Table 102. Mechanical and Physical Properties of Silver Solders (in Cast State)

Brand of solder	Temperature of test, in °C	Ultimate strength during extension, in kg/mm²	Yield point, in kg/mm²	Relative elongation, in %	Relative contraction, in %	Elastic modulus, in kg/mm², 10^{-3}	Impact toughness, in kgm/cm²	Hardness, HRC	Specific gravity, in G/cm³	Specific electrical resistance, in ohm × × mm²/m	Thermal conductivity, in cal/cm × × sec·deg	Coefficient of linear expansion × 10⁶ 20-100°	100-200°	200-300°
PSr 70	20	30-35	–	–	–	–	–	–	9.8	0.042	–	–	–	–
PSr 65	20	30-35	–	–	–	–	–	–	9.6	0.090	–	–	–	–
PSr 45	20	37-50	–	16-35	18-46	–	–	–	9.1	0.097	–	–	–	–
PSr 25	20	28	–	–	–	–	–	–	8.7	0.069	–	–	–	–
PSr 12M	20	18	–	–	–	–	–	–	8.5	0.076	–	–	–	–
PSr 40}	20	38-44	21-23	23-37	27-44	7.8-7.4	4.4	64-69	8.4	0.072	0.31	19.2	21.2	23.8
	-70	40-46	30-32	24	24-28	–	4.4–4.6	–	–	–	–	–	–	–
PSr 25KN	20	27-40	–	13-44	17-44	–	2.5	50-53	8.9	0.077	0.25	19.2	21.2	23.8

Note: Wide limits of mechanical data are explained by considerable porosity of certain poured samples.

Table 103. Strength of Joints Soldered by Silver Solders

Basic material	Ultimate strength of soldered joint, in kg/mm²: for shear (soldering by overlapping) PSr 40	PSr 45	PSr 25KN	PSr 37.5	PSr 12M	for break (soldering end-to-end) PSr 40	PSr 45	PSr 25KN	PSr 12M
1Kh18N9T...........	24-29	18-26	19-24	37-45	–	52-60	43-57	45-55	–
40KhNMA............	33-46	–	–	–	–	51-57	–	–	–
30KhGSA............	35-46	35-41	35-43	–	–	49-60	49-58	47-60	–
Copper.............	Is destroyed on basic material (σ_B base mat. = 25-26 kg/mm²)			–	–	Is destroyed on basic material		18-21	–
Brass L62	Is destroyed on basic material			–	20	24-33	25-32	25-32	19

Table 104. Strength of Soldered Joints at High Temperatures (Soldering by Overlapping)

Brand of solder	Basic material	Ultimate strength of soldered seam for shear, in kg/mm^2, at a temperature, in $^\circ C$			
		200	300	400	600
PSr 40	EN654	22-32	15-17	5-9	—
PSr 25KN	EN654	27-33	12-19	6-11	—
PSr 45	1Kh18N9T	—	16-24	14.5-15	3-4
PSr 37.5	1Kh18N9T	—	31-35	—	11-18
PSr 50Kd*	Low-carbon steel	17	9	4.2	—

*According to [51].

Table 105. Strength of Joints Soldered with Copper-Zinc Solders Basic Metal — Steel of St. 3 [52]

Brand of solder	Ultimate strength of soldered joint, in kg/mm^2	
	For extension	For shear
PMTs 48	27.8-34.0	18.0-25.0
L62	40.6-44.8	25.0-33.3
LOK 62-06-04	41.0-45.6	30.2-33.4

Table 106. Copper-Zinc Solders

Brand of solder	GOST	Chemical composition,* in %			Temperature,* in $^\circ C$		σ_B in kg/mm^2	σ in %	γ in g/cm^3	ρ in ohm·m^2/m	Solderable metals
		Cu	Sn	Si	beginning of fusion	full melting					
PMTs 36**	1534-42	36 ± 2	—	—	800	825	3	0-1	7.7	0.103	Copper, tombac and brass
PMTs 48	1534-42	48 ± 2	—	—	850	870	21	3	8.2	0.045	Copper, tombac and semitombac
PMTs 54	1534-42	54 ± 2	—	—	875	885	26	4	8.3	0.040	Copper, tombac, semitombac, iron and steel
Brass L62***	1019-47	62 ± 1.5	—	—	900	905	30	35	8.5	0.071	Copper and steel
LOK 62-06-04****	Non-standard	62 ± 1.5	0.4-0.1	0.6-0.2	900	905	—	—	—	—	Copper and steel

*Remaining zinc.

**Is applied rarely due to low mechanical properties.

***Ensures strong and ductile joints.

****Possesses improved technological and mechanical properties. Ensures higher density of soldered seam as compared to other copper-zinc solders.

Table 107. Heat-Resisting Solders [53], [54], [55]

Brand of solder	Chemical composition, in %								Temperature, in °C		σ_p in kg/mm^2	δ in %	γ in g/cm^2	Typical use
	Cu	Ni	Cr	Mn	Si	B	C	Other elements	beginning of fusion	full melting				
20	—	60-79	14-18	20-25	—	0.05	—	$\frac{Ti}{1.}$	1050	1180	46.2	3.5	—	Soldering of components from heat-resisting steels and alloys; soldered seams work up to 900°
Kolmonoy No. 6	—	72.3	15	—	4.5	3.75	0.45	$\frac{Fe}{4.0}$	1010	1070	—	—	—	The same, but due to brittleness of solder, gaps have to be less than 0.05 mm
85/15	—	—	—	15	—	—	—	$\frac{Ag}{85}$	960	972	—	—	—	As heat-resistant solder for joints working at a temperature not higher than 500°
PZhL-500	Base	27-30	—	—	1.5-2	0.2	—	$\frac{Fe}{1.5}$	1080	1100	62	30	8.6	Joining of components working at a temperature up to 600°
10	"	10	2-3	10	0.5	—	—	$\frac{Fe}{1-2}$		1050	—	—	—	Soldering of heat-resisting steels with molybdenum and heat-resisting steels among themselves. Soldered joints work up to 600°

Table 108. Strength of Joints Soldered by Heat-Resisting Solders

Brand of solder	Basic metal	Ultimate strength of soldered joinings, in kg/mm^2 at a temperature, in $^{\circ}C$				
		20		600		700
		Overlapping	End-to-end	Overlapping	End-to-end	Overlapping
20	EI481	—	—	—	—	20-24
PZhL 500	1Kh18N9T	45-50	58	22-26	42	—
PZhL 500	EI481	—	—	—	—	9-10
10	1Kh18N9T	35-36	—	22-23	—	—

Table 109. Solder for Soldering of Molybd num [53]

Composition of solder, in %	Temperature of liquid, in $^{\circ}C$	Innitial state	Ultimate strength of solder during extension, in kg/mm^2	Shear strength of soldered joint at 980°, in kg/mm^2
80Ni-14Cr-6Fe	1392	After hot rolling	5.3	13.2
55Co-20Cr-15W-10Ni	1427	The same	15.3	10.0
53Pd-47Ni	1204	—	—	6.6

Table 110. Solder for Soldering of Titanium, Zirconium and Their Alloys

Brand of solder	Chemical composition in %							Temperature in °C		σ_p in kg/mm²	δ in %	Soldered metal
	Zr	Be	Ti	Ni	Cu	Mn	Ag	beginning of fusion	full melting			
B4*	—	—	65	25	10	—	—	955	1000	Solder very brittle		Titanium and its alloys (in furn[illegible] in atmosphere of argon, [illegible] in vacuum). Gaps between components less than 0.05 mm
85/15	—	—	—	—	—	15	85	960	972	—	—	Titanium, zirconium and their alloys in atmosphere of argon or in vacuum
Silver	—	—	—	—	—	—	100	960	—	14-15	40-50	
95/5**	95	5	—	—	—	—	—	—	930	—	—	Zirconium alloys working in vapors of water at 360°

*From data in [58].

**From data in [57].

Table 111. Strength of Titanium and Zirconium Soldered Joints*

Brand of solder	Basic material	Ultimate strength of soldered joint in shear in kg/mm²
B4	VT1D	22-27
85/15	VT1D	23-28
Silver	VT1D	18-21
85/15	Zirconium	12-16
Silver	Zirconium	16-21

*Soldering by overlapping; induction heating in medium of argon.

Table 112. Solders with an Aluminum Base

Brand of solder	Chemical composition, in %					Temperature, in °C		σ_B in kg/mm^2	σ in %	γ in g/cm^3	ρ in ohm × × mm^2/m	Soldered metal
	Cu	Zn	Si	B	Al	beginning of fusion	full melting					
Silumin AL2*	≤0.8	≤0.3	$12^{+1.0}_{-2.0}$	—	Remaining	578	578	15-18	2-4	2.65	0.049	Aluminum, alloys AMTs and AV. Seams are stable under rigid corrosion conditions
P575A	—	20	—	—	80	575	620	—	—	—	—	Aluminum and alloy AMTs. Possible anodization and parkerizing of soldered components
35A	21 ± 1.0	—	7 ± 0.5	—	62	525	538	20-25	1-1.5	—	—	Aluminum and alloys AMTs, AMg and AV
34A	28 ± 1.0		6 ± 0.5	—	—	525	525	15-18	0.1	—	—	The same
36	20 ± 1.0	20 ± 1.0	3-3.5	0.1-0.2	Remaining	490	505	—	—	—	—	The same and L16

*Acording to GOST 2685-53.

Table 113. Solders with Zinc and Tin Base (For Soldering of Aluminum and Its Alloys)

Brand of solder	Chemical composition, in %							Temperature, in °C		σ_B in kg/mm^2	δ in %	γ in g/cm^3	ρ in ohm × × mm^2/m	Characteristic of soldered joint
	Zn	Cd	Sn	Cu	Al	Si	Other elements	beginning of fusion	full melting					
PSr5AKTs*	91-94	—	—	—	2-3	0.15	$\frac{Ag}{4.5}$	390	420	26	3	7.11	0.079	Seams have satisfactory corrosion stability under atmospheric conditions
48	88.5	—	—	4.0	7	—	$\frac{Co}{0.5}$	375	390	34	3	—	0.480	
70/30	70 ± 1	80 ± 1	—	—	—	—	—	266	350	—	—	—	—	Seams work satisfactorily under soft corrosion conditions
50/50	50 ± 1	50 ± 1	—	—	—	—	—	266	325	12	5	—	—	The same
VP250A*	35-39	02-0.3	remaining	0.4	—	—	$\frac{Sb}{02-03}$	—	—	—	—	—	—	Soldered joints have comparatively low corrosion stability and require protection against corrosion
10/90	10 ± 1	—	90 ± 1	—	—	—	—	199	205	4.7	50	—	—	

*According to [59].

Table 114. Magnesium solders [60]

Brand of solder	Chemical composition,* in %				Temperature, in °C		σ_B in kg/mm^2	δ in %	Standard use
	Al	Zn	Cd	Mn	beginning of fusion	full melting			
11380Mg	2.0-2.5	23-25	—	—	380	540	10-12	—	Soldering of magnesium and its alloys of brands MA1, MA2, MA3, MA5, MA8, ML5
1	25-27	1.0-1.5	—	0.1-0.3	435	520	9-12	0.2-0.3	The same
2	21-22	0.2-0.5	25-26	0.1-0.3	400	415	7-9	—	For nonflux sealing of small defects on components from alloy ML5

*Remaining Mg

Solders and Property of Soldered Joints

The most wide-spread solders, and also their properties and properties of soldered joints are given in Tables 97-114.

All tin-lead solders (Table 97), with the exception of POSS 4-6, ensure joints of satisfactory quality and differ in technological properties; the most technological is solder POS-61. It is inexpedient to use pure tin for soldering because of possibility of appearance "of tin plague" and full loss of strength of soldered joints in use at a temperature lower than 18°C.

Of silver solders (Table 101), in electrical engineering and also in vacuum technology, solder PSr 72, which possesses high electrical conductivity and does not contain components that are highly volatile in vacuum is most widely used. In machine building solder PSr 40, having the lowest temperature of fusion (605°) and giving high-quality soldered joints is widely used. Sometimes, for the purpose of economy of silver, one uses copper-phosphorous solders, containing 7-8% phosphorus, for instance alloy MFZ (GOST 4515-48). These solders ensure sufficient strength of joints in soldering of copper and bronzes, but in soldering of brasses and nickel alloys, seams are brittle.

Copper-zinc solders PMTs 36, PMTs 48 and PMTs 54 are used rarely due to low strength of soldered joints, in comparison with solders L62 and LOK 62. During furnace soldering of steels in reducing gas media, the solder frequently used is pure copper, which gives sufficiently strong and ductile soldered joints.

During soldering of heat-resisting steels and alloys, preference should be given to those heat-resisting solders which possess the biggest ductility, since in case of application of brittle solders

(type "Kolmonoy" and others), it is possible to obtain ductile joints with only very small gaps (less than 0.05 mm) and prolonged holding in process of soldering. Sufficient prolonged heat resistance of soldered joints (at 700° and above) can be ensured by use of solders of nickel-chrome base of type No. 20 (Fig. 84 according to V. A. Gorokhov and M. I. Skripov).

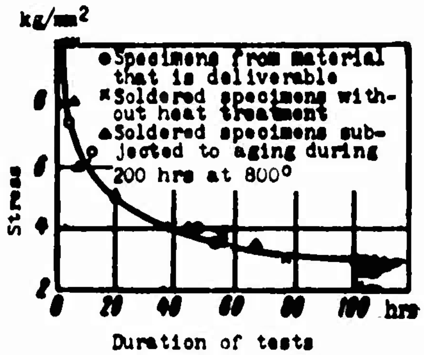


Fig. 84. Prolonged strength of specimens from alloy KhN78T at a temperature 800°.

During soldering of molybdenum, fully satisfactory heat-resisting joints are ensured by solders shown in Table 109. In those cases, when joints from molybdenum and tungsten are not required to have strength at high temperatures, it is possible to apply copper and silver solders.

Those given in Table 110, and also other known solders in soldering of titanium, zirconium and their alloys give strong enough, but insufficiently ductile joints.

During soldering of aluminum, the most reliable joints are obtained by use of solders on the base of aluminum (Table 112). The biggest corrosion stability is shown by joints soldered with Silumin containing 88% aluminum. Joints, made with solders on the base of zinc, have a strength and corrosion stability lower than joints soldered with solders on the base of aluminum, but significantly higher than in case of application of tin solders.

The process of soldering of magnesium alloys has been studied comparatively little and data on strength and corrosion stability of soldered joints are insufficient.

For soldering of beryllium, it is recommended to apply aluminum,

aluminum-silicon (12% Si), pure silver, eutectic alloys aluminum-silver and silver-copper (28% Cu). For soldering of beryllium with nickel, stainless steel and copper, it is possible to apply copper, silver and PSr 72 as solder.

Fluxes and Atmospheres

Soldering fluxes have to satisfy following basic requirements:

1) remove oxides from surface of basic metal and solder by means of their dissolution or reduction, with formation of fusible slag;

2) promote wetting by solder of combinable surfaces and to ensure flow of solder in gaps between them;

3) have temperature of active effect lower than temperature of fusion of solder, but temperature of loss of fluxing ability – significantly higher than temperature of soldering.

During soldering of steels, and also copper and nickel alloys with refractory solders, one uses fluxes with a base of borax, boric acid and fluoride joints; during soldering of aluminum alloys – fluxes on the basis of halide joints of alkali and alkali earth metals. In case of application of tin-lead solders, one uses fluxes with a base of zinc chloride or hydrazine hydrochloride, and also with a base of rosin and other orgainic compounds.

Fluxes for soldering are basically used in the form of powder, paste and liquid. For preparation of a paste, one uses usually water or alcohol, with which powdered f ux is mixed. Fluxes are applied on edges of combinable components prior to soldering. Basic data on one of the most widespread fluxes for soldering of metals are given in Tables 115-117.

Table 115. Fluxes for Soldering Iron, Copper, Nickel and Their Alloys with Fusible Solders

Brand of flux	Components	Composition (by weight) in %	Temperature interval of fluxing action, in °C	Soldered metal
–	Zinc chloride Water	25-40 Remaining	280-350	Steel, copper and copper alloys, nickel and nickel alloys – tin-lead solders. After soldering, remainders of flux are thoroughly washed off with running water to avoid corrosion
–	Zinc chloride Ammonium chloride Water	40 10 50	180-320	
–	Zinc chloride Hydrochloric acid (sp. gr. 1.19) Water	25 25 50	280-350	Stainless steels – tin-lead solders with lead base. After soldering thorough washing of components by water and weak solution of soda is necessary
KE	Rosin Ethyl alcohol	25 75	180-300	Copper – tin-lead solders containing 30% and more tin. Remainders of flux cause practically no corrosion
–	Triethanolamine Stearin Paraffin	3-5 30-40 Remaining	180-280	Copper and lead – tin-lead solders. Remainders of flux cause practically no corrosion
LMI-120	Rosin Diethylamine hydrochloride Triethanolamine Ethyl alcohol	24 4 2 70	180-300	Copper, brass, galvanized iron, and steel. Remainders of flux cause practically no corrosion
FIM	Orthophosphoric acid Ethyl alcohol Water	10 45 45	240-350	Steel, nickel and its alloys
LM-1	Rosin powder Orthophosphoric acid (pH 1.6-1.7) Ethyl alcohol	6 32 62	240-350	Construction and stainless steels with solders containing over 30% tin. For soldering of copper and its alloys, not recommended. Remainders of flux do not evoke corrosion of stainless steel
LK-2	Ammonium chloride Zinc chloride Rosin powder Ethyl alcohol	1 3 30 66	180-300	Copper, brass and galvanized iron. Remainders of flux removed by acetone or turpentine
KC	Rosin Solicylic acid Triethanolamine Ethyl alcohol	30 2.8 1.4 Remaining	150-300	Component from brass, bronze, German silver. Remainders of flux removed by alcohol or other solvent
–	Hydrogine hydrochloride Rosin Ethyl alcohol	5 25 70	150-300	Copper and copper alloys. Remainders of flux removed by acetone or turpentine.

Table 116. Fluxes for Soldering of Aluminum, Magnesium and Their Alloys

Brand of flux	Components	Composition (by weight) in %	Temperature interval of fluxing action, in °C	Soldered metal
34A	Zinc chloride Sodium fluoride Lithium chloride Potassium chloride	8 10 32 50	450-650	Aluminum and its alloys: AMTs, AMg, AV, AK6, D16, V95 and Silumin. Remainders of flux should be thoroughly removed after soldering
F59A	Cadmium fluoborate Zinc fluoborate Ammonium fluoborate Triethanolamine	10 2.5 5 82.5	180-250	Aluminum and alloy AMTs during assembly work with solders 10/90 and POS-61 [59]
17	Eutectic* ($3KF \cdot AlF_3 + AlF_3$) Lithium chloride Potassium chloride	8 41 51	560	Aluminum and its alloys (composition of salt bath) [60]
6	Aluminum oxide Sodium fluoride Carnallite, fused	4 8 88	450-650	Magnesium casting, sealing of defects with solders with a magnesium base. Remainders of flux should be thoroughly removed after soldering [59]
12	Cryolite Sodium fluoride Sodium chloride Lithium chloride Potassium chloride	2 8 9 49.5 31.5	450-650	For soldering of magnesium and its alloys. Remainders of flux should be thoroughly removed after soldering [60].

*Consists of 46% KF and 54% AlF_3.

Table 117. Fluxes for Soldering with Refractory Solders

Brand of flux	Components	Composition in weight parts	Temperature interval of fluxing action, in °C	Soldered metal
200	Borax........................ Boric acid................... Calcium fluoride............	20 70 10	850-1200	Construction, stainless steels and heat-resisting alloys with copper, copperzinc and heat-resisting solders;
200-a	Borax dehydrated............ Boric anhydride............. Calcium fluoride............	20 65 15	850-1200	The same, but flux, waterless; ensures more dense seams than flux No. 200. During application on component is mixed with ethyl alcohol or is applied in the form of dry powder
201	Borax dehydrated............ Boric anhydride............. Calcium fluoride............ Alloy* (Cu-Al-Mg)...........	12 77 10 1	850-1200	The same, but more active than 200 and 200-a
209	Calcium fluoride dehydrated. Calcium fluoborate.......... Boric anhydride.............	42 23 35	600-850	Construction stainless steels, and also heat-resisting alloys with silver and copper-phosphorous solders
284	Calcium fluoride dehydrated. Calcium fluoborate.......... Boric anhydride.............	35 40 25	450-750	
18-B	Calcium fluoride dehydrated. Boric acid..................	40 60	650-850	Stainless steels and bronze copper-phosphorous and silver solders with temperature of fusion at 650-800°C

*Consists of 48 Cu-48 Al-4 Mg.

Sometimes, solid fluxes cannot be applied because of difficulty of removal of their remainders from components after soldering, possibility of appearance of corrosion in zone of soldered joint, and also possibility of obstruction of narrow channels with residues of flux in process of use of article. In shown cases, solder is produced in reducing of inert atmosphere and also in vacuum.

As a reducing atmosphere during soldering of steels, nickel alloys, molybdenum and tungsten, one usually uses hydrogen, dissociated ammonia and boron trifluoride. During soldering of low-alloy steels, one uses also products of incomplete combustion of natural or generator gas. Soldering of steels, bronzes, nickel alloys, titanium, molybdenum, tungsten is fully satisfactory in inert gases, for instance, in argon I of composition [*]. For soldering of zirconium, tantalum and niobium, specially thorough purification of inert gases from impurities of nitrogen, oxygen and vapors of water is required.

Soldering of steels and other above-mentioned metals without application of fluxes is possible in vacuum during furnace or induction heating. Cleanliness of surface of components and quality of soldered joint depend on degree of vacuum. For soldering of the most wide-spread metals — steel, bronze, and nickel alloys — one usually uses vacuum of 10^{-2} to 10^{-3} mm of mercury column.

Technological Peculiarities of Soldering of Different Metals

Soldering of low-carbon, low-alloy steels does not present any difficulties. For soldering, one uses tin-lead solders, copper, copper-zinc and silver solders. Solders containing phosphorus are unfit for soldering steel, since seam obtained is brittle.

*Illigible in original text [Tr. Ed. note].

For low-carbon low-alloy steels all forms of soldering are used; the widest use is made of soldering by burner, in furnace and by induction. During soldering, it is necessary to apply corresponding flux or atmosphere. Soldering of high-carbon and tool steels should be performed prior to hardening or combined with heating for hardening.

Soldering of stainless steels and heat-resisting alloys is possible by usual methods, but, besides, one should consider that due to presence on their surface of chemically stable oxides of alloy elements and other peculiarities, selection of solders, fluxes and method of heating is of more important value than during soldering of usual metals. Majority of stainless steels and heat-resisting alloys during soldering should be heated and cooled fast, in order to bring to a minimum separation of carbides which significantly lower their corrosion stability. High-nickel alloys are subject to corrosion cracking under stress in presence of molten solder; therefore, their soldering should take place in annealed state, and assembled assemblies should not experience stresses in process of soldering.

Copper and copper alloys to soldering are easily used with standard solders with application of simplest fluxes.

During soldering of beryllium and aluminum bronzes, due to presence of a dense chemically stable flim, there is need of thorough preparation of surface and application of more active fluxes than during soldering of copper. Soldering of heat treated beryllium bronze should be with low-temperature silver solders (for instance, PSr 40), with fast, local heating for preservation of mechanical properties of basic metal.

Brasses are soldered by existing methods. However, soldering

in furnace with reducing hydrogen atmosphere is usually not applied; in separate cases (soldering of brass with steel), soldering is carried out in protective atmosphere, but, besides, one uses fluxes in order to avoid evaporation and oxidation of zinc.

Lead brasses with a lead content up to 3% can be soldered with copper-phosphorous or silver solders with application of a corresponding flux. For a large content of lead, joints are less strong, and process of soldering is significantly hampered.

During soldering of tungsten, special attention should be allotted to preparation of surface: for this purpose, one uses etching with a mixture of nitric and hydrofluoric acids or machining. As a protective atmosphere during soldering, one can use hydrogen, a mixture of nitrogen with hydrogen, neutral gases and vacuum. For soldering of tungsten one uses copper, silver and nickel solders, platinum, gold.

During soldering of molybdenum, it is recommended to apply fast heating (induction or other). Due to significant oxidation of molybdenum and embrittling action of oxides, soldering in air with oxyacetylene burner is not recommended. As a protective atmosphere, one can use the same medium, as during soldering of tungsten.

Titanium and zirconium can be soldered in a furnace, by induction method and method of resistance in vacuum, in medium of argon or helium. Besides, specially thorough purification is required of inert gases from impurities of nitrogen, oxygen and vapors of water. One can not apply nitrogen, hydrogen, or their mixtures for soldering, since with these gases titanium and zirconium form brittle joints. During soldering of titanium and zirconium with silver or silver solders fast heating is recommended for decrease of brittle diffusion zone.

Soldering of aluminum alloys can be carried out by standard methods — burner, in furnace, by induction heating, in salt baths. Due to high chemical stability of oxidized film of aluminum during soldering, it is necessary to apply active fluxes (Table 116). For joining of critical components of aluminum alloys, one should apply refractory solders with an aluminum base, ensuring sufficient strength and corrosion stability of soldered joints.

With solder 34A it is possible to solder aluminum and certain of its alloys. It is most easy to solder alloys AMts, AV and AMG; more difficult — duralumin, AK4, V95 and foundry alloys, having a lower temperature of fusion.

Soldering of duralumin with solder 34A is possible only during manufacture of small components and with great caution, in order to avoid overburning or melting of basic metal. Due to significant heating during soldering, duralumin passes into annealed state with a loss of not less than 30% strength in zone of soldering, and, in case of overburning, its strength decreases almost twice.

Control of Quality of Soldered Joints

Quality of soldered seams depends to a significant degree on correct selection of construction of joint, solder, flux, or protective atmosphere and technology of soldering. During manufacture of components, and assemblies by method of soldering, one should subject to strict control not only finished production, but also process of soldering and even preparatory operations.

Control during preparation for soldering consists of a check of conformity of material of article, solder and flux to brands shown on drawing, accuracy of trimming including magnitude of gaps, overlap

and other parameters of joint, and also cleanliness of surface of combinable details.

In process of soldering, it is necessary to control temperature and time of holding, not allowing overheating of components and solder.

After soldering follows acceptance and test of soldered articles. In the beginning, soldered joints are inspected. Shaft of solder all over perimeter of seam should be clean, smooth, without pores, blowholes, outside inclusions and unsoldered areas. After that, articles, depending upon their construction and use, can be subjected to radioscopy by X-rays; pneumatic and hydraulic pressing for density; tests for vibration strength, thermal stability and so forth. In parallel with articles, one can solder control specimens for mechanical tests for shear, break and other forms of loads.

During radioscopy by X-rays, one reveals hidden defects of soldering — unsoldered areas, porosity and small cracks. Besides, one should consider that soldered joints, as a rule, have pores, quantity of which should be limited by technical conditions depending upon requirements imposed on article. In most cases, unsoldered areas (voids and pores), distributed evenly all over seam, can occupy up to 25% of total area of soldered joint; for specially critical joints, unsoldered spaces usually do not have to exceed 15% of total area [64]. In separate cases, more rigid requirements can be imposed on soldered joints.

Presence of small cracks in seam or in near-seam zone is considered as rejects. Reason for appearance of cracks may be incorrect selection of gaps, without calculation of difference of coefficients of thermal expansion of combinable materials, and also careless

treatment of soldered article during hardening of solder.

Sometimes, one uses method of test with destruction of soldered components. Besides, one makes selective tests of a small part of finished production. On the basis of obtained results, one accepts or rejects the entire lot.

Defective places of soldered seams may be soldered with subsequent check of quality of soldering. Soldering of the same place is permitted not more than 2 times. Otherwise, seam is resoldered or article is rejected.

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CHAPTER IV

THE TECHNOLOGY OF THERMAL AND CHEMICAL-HEAT TREATMENT OF METALS

THERMAL AND CHEMICAL-HEAT TREATMENT STEEL

Characteristic and assignment of processes. Process of thermal (or chemical-heat) treatment of steel consists of three consecutive stages: heating to a required temperature at a definite speed, holding at this temperature for a required time and cooling at a given speed. A change of these factors determines different properties of the steel.

These processes of heat treatment give the steel article the required properties throughout all its volume or in part of its volume.

These processes, which proceed with a diffusion saturation of the steel surface with different elements and which lead to a change of chemical composition of the surface layer of the steel article, are called chemical-heat treatment. Among these processes are cementation (carburization), nitration, cyanidation, sulfiding, sulfating, calorizing, chromium-plating, siliconizing, zincing, borating and others.

During the chemical-heat treatment the heating, holding and cooling of the steel is conducted in an active medium of definite composition, which saturates the surface of the steel with different elements.

Heat treatment of steel. Annealing, normalization, hardening, leave, aging and treatment by cold are among the processes of heat treatment.

Annealing the steel causes (due to phase recrystallization) a change of the magnitude of the grain, a degree of dispersiveness of phases and a resultant equilibrium of structures of austenite disintegration.

According to assignment there are complete, incomplete, low-temperature, diffusion and recrystallizational annealing.

Complete annealing is heating steel to a temperature, exceeding by 30-50°C the upper critical point Ac_3, holding at this temperature and slowly cooling to 400-600°C, most frequently with furnace. Further cooling can be produced at high speed.

Annealing is applied chiefly for castings, rolling and forgings from hypoeutectoid carbonic and alloy steel (for instance, steel 60, 50G, 60G, 65G, 40Kh, 45Kh, 40SKh, 40KhN, 45KhN, 37KhNZA, 45KhNMFA, 35KhMA, 38KhMYuA, 35KhGS) for the purpose of reducing hardness, improving workability by cutting (Table 1) decrease or eliminating internal stresses in casing forgings and welded articles, increasing the plastic and viscous properties (Table 2) while lowering the ultimate strength and limit of fluidity, preparing the structure for subsequent heat treatment and decreasing the structural heterogeneity.

Table 1. Influence of Complete Annealing on Workability when Cutting (when Sharpening) Steel*

Brand of steel	Hot-rolled		Annealed	
	HB	Workability in %	HB	Workability in %
30	190	60	150	70
30G	< 220	60	< 190	70
30KhNZ	< 240	40	180-220	55
35	200	55	165	70
40	255	45	180	70
45G	< 230	45	< 210	70

*The workability, when cutting of cold-drawn automatic steel A12.

Table 2. Influence of Full Annealing on Mechanical Properties of Hot-Forged and Poured Steels

Brand of steel	Condition of steel	HB	σ_B in kg/mm^2	δ in %	ψ in %	a_H in kg·m/cm^2
40	After forging................	< 217	68	20	43	–
	After forging and complete annealing..................	< 197	58	22.5	57	–
45	Casting before annealing.....	–	48	10	35	5
	Casting after complete annealing..................	–	43	18	55	8
55	After rolling................	241-255	71	15	38	–
	After rolling and complete annealing..................	207-229	58.5	22.5	43	–
65	After forging................	–	98	15	47	–
	After forging and complete annealing..................	–	62	24	59.5	–
70	After stamping...............	–	100	5	6.3	–
	After stamping and complete annealing..................	–	75	22.5	61.5	–
45G	After rolling................	241	83	16	49	0.7
	After rolling and complete annealing..................	187	69	21	54	1.35

The microstructure of steel in its poured state possesses big grain with a coarse separation of ferrite. Annealing of poured steels leads to an obtaining of a fine-grained structure with evenly distributed grains of ferrite.

Flocs (small cracks) frequently appear in large (section more 50 mm) forgings from alloy steels, especially chrome-nickel with a content Mo or W. The most effective method of prevention of formation of flocs is a delayed cooling of steel after stamping or forging, and also annealing at a temperature of perlitic transformation.

For a reduction of the duration of the process of complete annealing of alloy steels, isothermal annealing, consisting of heating steel to a temperature in the interval of transformations or above it, holding at this temperature and accelerated cooling to a temperature lower than the interval of transformations, holding at this temperature and final cooling, usually in air, is applied. For instance, for improving the workability when cutting and obtaining a heightened cleanness of surface during gear cutting, milling and extension of slits for parts, prepared from steel 40KhNMA, isothermal annealing at 760°C with fast cooling to 635°C, holding at this temperature for 4-6 hours and further cooling in air is applied. As a result of this treatment the steel obtains its structure from thin-laminar perlite, grains of ferrite and fine-grained cementite (NV 192-212).

Incomplete annealing is heating steel to a temperature above Ac_1, but lower than Ac_3, holding at this temperature and slowly cooling. It is used for hypereutectoid steels and for rolling and forgings from hypoeutectoid steels for the purpose of improving workability while cutting and removing internal stresses. A partial

change of properties occurs (due to partial phase recrystallization) during incomplete annealing.

A variety of incomplete annealing is spheroidizing annealing, which includes heating the steel to a temperature somewhat higher than the point Ac_1, holding at this temperature and subsequent slow cooling. This is applied for the purpose of reducing hardness for the improvement of workability while cutting of hypereutectoid (tool) steel and certain brands of hypoeutectoid alloy steels. For instance, for tool steels with a content of C > 0.65% a spheroidizing annealing is applied at 740-760°C; for parts prepared from steel 35KhGS, spheroidizing annealing is conducted at 780°C, as a result of which the structure of granular perlite is obtained, which permits the application of high speed cutting during rough and finishing sharpening and preliminary milling of details.

For steel ShKh15, annealing at 780-800°C is applied whereby the structure of granular (and point) perlite is obtained.

Low-temperature annealing (high tempered) is heating steel lower than point Ac_1, holding at this temperature and subsequent cooling, most frequently in air. This is applied mainly for removing internal stresses after the welding of articles and after mechanical (rough) treatment of forgings from alloy steels, and also for the purpose of reducing hardness and improving the workability while cutting high-alloy steels, for instance brands 12Kh2N4A, 20Kh2N4A, and 18Kh2N4VA, the temperature of annealing of which is equal to 650-670°C.

The same annealing for above mentioned steels is applied later on in their cementation for the purpose of decreasing the content of austenite in the carburized layer.

The influence of low-temperature annealing on the magnetic properties of steel, in comparison with complete annealing, is given

in Table 3.

Table 3. The Influence of Annealing on the Magnetic Properties Steel (0.3% C;0.85% Mn; 0.084% Si)

Field tension in э	Magnetic induction of steel		
	in forged state	after low temperature annealing at 700°C	after complete annealing at 900°C
3	325	837	550
7.5	2,387	8,250	4,750
12	5,050	11,550	8,700
30	12,200	15,600	14,000
50	15,450	16,850	16,000
100	18,200	18,250	17,700
150	19,100	19,000	18,900
200	19,700	19,450	19,500

Diffusion annealing (homogenization) is heating steel to a temperature higher than point Ac_3 by 150-300°C, prolonged holding (practically 8-15 hours) at this temperature and subsequent slow cooling. This is applied chiefly for large steel castings of alloy steels for the purpose of equalizing (by means of diffusion) chemical heterogeneity of grains of solid solution and decreasing the liquation. Diffusion annealing evokes an increase in the dimension of the grain, making it necessary to produce additional complete annealing or normalization for the purpose of breaking up the structure.

Recrystallizational annealing is used for steel deformed in cold state (riveted, cold worked) (cold-stamped articles, cold-rolled sheet and tape, cold-drawn rods and wire), which, due to riveting, becomes durable and hard with a decrease in its plasticity (Table 4). The purpose of this annealing is a restoration of initial properties of the steel — lowering of hardness, a restoration of plasticity and viscosity with a certain lowering of durability (Table 5), obtaining

of equiaxial undeformed grains, the removal of internal stresses and an improvement of deforming capacity during subsequent cold treatment – drawing, stamping, rolling.

Table 4. The Influence of Cold Rolling on the Mechanical Properties of Steel

Brand of steel	Degree of deformation (decrease of the section) during cold rolling	HB	σ_B in kg/mm^2	δ in %
10 (0.12% C)	Initial state 20 50	90 160 200	60 110 130	30 10 7
35 (0.34% C)	Initial state 20 50	95 180 220	85 120 160	30 6 4
45 (0.46% C)	Initial state 20 50	160 210 240	120 150 180	20 8 3

Recrystallizational annealing consists in heating steel higher than the temperature of recrystallization* by 150-250°C, holding at this temperature and subsequent cooling.

Normalization differs from full annealing by the nature of its cooling, which, after holding details at the processing temperature; is produced in air. Thus, steel is obtained with a somewhat higher hardness and fine-grained structure than with annealing, which causes higher values of tension limit and limit of proportionality with a certain lowering of plasticity (Table 6). Normalization is used for correcting the structure of a welded seam, levelling of the structural heterogeneity (castings and forgings), obtaining a fine-grained

*Temperature of recrystallization $T_{\text{абс. рекр}} = 0.4\,T_{\text{абс. плавл}}$ (by Bochvaru).

structure, improving the workability when cutting carbonic and alloy steels with a low and average content of carbon (for instance, steel brands 10, 15, 20, 30, 35, 40, 45, 50, 50G, 20Kh, 15KhF, 20NM, 18KhGT, 18KhGMA, 12KhN3, 12Kh2N4, 20Kh2N4, 20KhN3A, 40KhS, 40KhNMA, 38KhMYuA). For certain brands of high alloy and average alloy steels (50G, 45Kh, 35SG, 40SKh, 20Kh2N4A, 18Kh2N4VA), after normalization, high-temperature annealing is necessary for improving the workability when cutting. Normalization is used also for preparing the structure for subsequent heat treatment (hardening) and increasing the plasticity and viscosity of hot-deformed steels (Table 7). Furthermore, normalization is applied after cementation of details for the purpose of decreasing the quantity of free carbides and resorption of the carbide lattice in the carburized layer (in avoiding cracks when grinding, hardening and utilizing details) and obtaining a fine grain uniform structure in the core of articles after cementation.

Table 5. The Change of Durability and Plasticity of Steel During Cold Deformation and Recrystallizational Annealing

Brand of steel	State of the steel	σ_B in kg/mm^2	δ in %	ψ in %	a_H in kg·m/cm^2	HB
20	Initial — normalization at 900°C	40	25	—	—	—
	The same for riveted (cold worked)......................	50-85	4	—	—	—
	After riveting and recrystallizational annealing..........	32-55	20	—	—	—
40	Initial — normalization........	63	18	—	8	187
	The same and riveted (cold worked)......................	87	5.5	—	2.8	241
	After riveting and recrystallizational annealing..........	58	21	—	6.5	149
ShKh9	Initial — annealing...........	60-73	—	—	—	—
	The same and riveted (cold worked)......................	110	—	30	—	—
	After riveting and recrystallizational annealing..........	70	—	60	—	—

Table 6. Comparison of Mechanical Properties of Steel in Annealed and Normalized State

Brand of steel	Heat treatment	HB	Mechanical properties				
			σ_B in kg/mm^2	σ_s in kg/mm^2	δ in %	ψ in %	α_H in kg·m/cm^2
50	Complete annealing. Normalization......	179-228 187-235	55-75 63-80	>29 >34	>15 >11	— —	— 5-6
40Kh	Complete annealing. Normalization......	179-207 207-217	60-70 73-78	— —	15-20 14-18	45-50 48-54	5-9 6-8
50G	Complete annealing. Normalization......	207 248	74 111	49 55	23 20	59 52	— —
40KhH	Complete annealing. Normalization......	202 228	66 77	46 54	26 21	56 51	— —

Table 7. The Influence of Normalization on the Mechanical Properties of Hot-Deformed Steels

Brand of steel	Condition of the steel	σ_B in kg/mm^2	δ in %	ψ in %	α_H in kg·m/cm^2	HB
40	After rolling.......... The same for normalization..............	65 60	17 18	43 47	7 —	— —
50	After rolling.......... The same for normalization..............	74 65	14 26	35 40	4 —	250 164
20G	After rolling.......... The same after normalization..............	57 58	23 24	— 68-71	22 25	166 159
50G	After forging.......... The same after normalization..............	75-81 69-72	13-18 20-23.5	16-25 33.5-43.5	1.2-4.2 4.5-6	228 187
15Kh	After rolling.......... The same after normalization..............	51 47	25 30	73 77	13 13	156 143
40Kh	After rolling.......... The same after normalization..............	73 68	16-19 20	67 51-53	— 5.5	217 197-207

Hardening steel is the process of heat treatment, which produces structures of austenite, martensite, troostite. It is used for casings, forgings, stampings and mechanically treated details for the purpose of increasing hardness, obtaining the required physicomechanical (high characteristics of durability, resistance to wear, corrosion resistance, magnetic and electrical properties).

Hardening consists of heating steel to a temperature above or at the interval of transformations, holding at this temperature and subsequent cooling, usually at great speed (in water solutions of salts NaOH, NaCl, in water, oil, in salt solutions, in air).

The influence of this type of tempering medium (and temperature of tempering) on the characteristics of durability and plasticity of steel 40 is given in Table 8.

Table 8. The Mechanical Properties of Hardened-Steel Brand 40, Depending Upon the Type Tempering-Means and Temperature of Tempering

Index of durability	Temperature of tempering in ^{o}C	Hardening		
		At $850^{o}C$ in oil at $45^{o}C$	At $820^{o}C$ in water at $35^{o}C$	At $820^{o}C$ in an 8% solution of NaOH at $35^{o}C$
σ_T in kg/mm^2	300 400 500	68 62 55	100 90 75	112 95 80
σ_B in kg/mm^2	300 400 500	88 78 68	105 100 85	126 110 100
δ in %	300 400 500	16 18 20	9 12 14	5 12 14

Note: Heat treatment of blanks with a diameter of 25 mm; breaking samples with a diameter 20 mm were cut from the central part of blanks.

A distinction is made among complete, incomplete, isothermal and step hardening.

Complete hardening is heating steel to a temperature, exceeding by 30-50^{o}C point Ac_3 for hypoeutectoid steels (for hypereutectoid steels — higher than point Ac_1 by 30-50^{o}C), holding at this temperature

and cooling at great speed in order to obtain, most frequently, a martensite structure (Fig. 1, I, II).

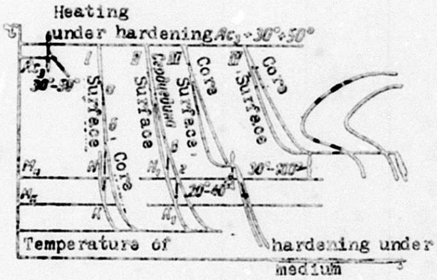

Fig. 1. Schematic curves of cooling steel during common (complete) hardening: I - in water; II - in oil; III - during step hardening; IV - during isothermal hardening.

This is used for castings, forgings and mechanically treated details for the purpose of obtaining a high hardness, high mechanical properties and resistance to wear (Table 9 and 10).

Incomplete hardening is heating steel to a temperature, at the interval of transformations (above Ac_1, but lower than Ac_3), holding at this temperature and subsequent cooling at great speed. As a result of incomplete hardening nonuniform structure is obtained, consisting of austenite, martensite, troostite, as with complete hardening, ferrite — for hypoeutectoid steel and carbides — for hypereutectoid steels. It is applied chiefly for hypoeutectoid carbon steel.

Isothermal hardening is heating steel to a temperature higher than point Ac_3 by 30-50°C, holding at this temperature, cooling in a medium* at a temperature above the beginning of martensite transformation M_H by 30-100°C for isothermal transformation of austenite and subsequent cooling (outside this medium) at a given speed (Fig. 1, IV). This is applied chiefly for details of small section of high-carbonic and alloy steels (for instance, brands 85, 65G, 30KhGS, 37KhS, 50KhFA, 55S2, 60S2A and others) and as an instrument for the purpose of decreasing stresses and deformations and obtaining a high hardness and high values of plasticity, durability and, especially, viscosity, most frequently without subsequent tempering. For most construction

*The characteristics of media applied for cooling during isothermal hardening are shown on p. 494.

Table 9. The Mechanical Properties of the Core of Cemented Steels after Hardening and Low-Temperature Tempering

Brand of steel	Heat treatment			Mechanical properties not less than					
	Hardening		Tempering in °C*	σ_B in kg/mm²	σ_s in kg/mm²	δ in %	ψ in %	a_H in kg·m/cm²	HB
	Temperature in °C	Medium							
10	780 800	Water	180 200	40	25	25	55	-	~ 137
20	780 800	Water	180 200	50–60	28–35	18	45	–	145–160
15G	780 800	Oil	180 200	50	30	17	45	-	140–160
20G	850	Water	300	125–130	–	6.5	57–60	8–9	~ 3[illegible]
15Kh	780 800	Water	180 200	62	38	15	45	6	179
20Kh	780 800	Water	180 200	65	40	13	40	5	197
20KhG	800 820	Oil	180 200	80	60	10	40	6	229
15KhF	780 800	Oil	190 210	80	60	9	50	7	241–255
15KhM	840 820	Oil	160 190	125	–	–	–	14	–
18KhGM	870	Oil	210	110	90	7	50	9	285–388
18KhGT	800 820	Oil	180 200	115	95	10	50	8	332–375
15NM	780 800	Oil	190 210	85	75	10	50	9	241–255
12KhN2	780 800	Oil	180 200	80	60	12	50	9	229
12KhN3	780 800	Oil	180 200	85	70	10	50	8	241
20KhN3A	800	Oil	180	–	–	–	–	10–13.7	363–398
12Kh2N4	780 800	Oil	160 180	100 130	80 110	10 9	55 45	10 8	321–420
20Kh2N4	780 800	Oil Oil	160 180	125–145 145–160	115 130	7 7	45 40	8 7	321–444 321–444
18Kh2N4VA	810 820	Oil	160 180	115	85	11	50	12	331–388
12Kh2N3MA	780 800	Oil	180 200	120	95	10	50	9	328–396
20KhGR	880 880	Oil	200	135–150	111–125	13–14	60–63	11–12	364–444
15Kh2GN2TRA	820 880	Oil	160	127–138	116–12[illegible]	13–13.5	61.5–63	12–13.0	364–387

*Limits of temperatures are shown.

Table 10. Mechanical Properties of Forgings from Carbonic Alloy Steels after Improvement

Brand of steel	Hardening		Tempering		Mechanical properties						
	Temperature in °C*	Cooling medium	Temperature in °C*	Cooling medium	σ_B in kg/mm²	σ_s in kg/mm²	δ in %	ψ in %	a_H in kg·m/cm²	HB	Dimension of a section of forgings in mm
[illegible]	[illegible]	Water	580 630	Air	60	32	18	40	5	192–229	To 100
[illegible]	[illegible]	Water	580 640	Air	65	35	17	38	4	192–235	To 100
[illegible]	[illegible] 840	Water	580 620	Air	70–80	37–42	15–17	40–45	4–5	212–235	To 80

Table 10 (Continued)

Brand of steel	Hardening: Temperature in °C*	Hardening: Cooling medium	Tempering: Temperature in °C*	Tempering: Cooling medium	Mechanical properties: σ_B in kg/mm²	σ_S in kg/mm²	δ in %	ψ in %	a_H in kg·m/cm²	HB	Dimension of a section of forgings in mm
50G	820 840	Oil	560 600	Air	80	65	8	40	3.5	241–285	До 60
50S2G	820 840	Oil	600 660	Water	80	45	12	35	4	241	» 100
30Kh	850 870	Water	550 570	Water	72	50	14	45	5	212	» 100
35Kh	840 860	Oil	610 630	Water	65	45	14	45	5	187	» 100
35KhG2	810 830	Oil	620 660	Water	85	70	12	45	8	235–269	» 100
40KhGM	850	Oil	560	Water or oil	110	100	12	50	7	321–347	» 100
27SG	870 920	Water	600 420	Water	100	80	10	45	9	—	» 25
30KhGS	860 890	Oil	640 660	Water	75	65	12	45	6	241	» 100
35KhGS	860 880	Oil	600	Water	100	75	7	45	6	285	» 60
40KhFA	870 890	Oil	630 660	Water	90	75	10	50	9	269	» 60
45KhNMFA	860 880	Oil	550 600	Air	105	90	9	40	8	321–363	» 100
38KhMYuA	930 950	Oil	600 670	Water	100	85	15	50	9	285	» 60
25KhNVA	850	Oil	560	Air	110	95	11	45	9	—	» 25
40Kh	830 850	Oil	540 570	Water	78	55	12	40	4	236	» 100
45Kh	820 840	Oil	600 630	Water	85	65	10	45	5	241	» 100
35SG	890 910	Water	580 620	Water	85	65	15	40	6	207	» 60
33KhS	920 940	Water	620 640	Water	95	75	15	45	6	285	» 60
37KhS (49SKh)	890 900	Oil	600 650	Water	100	80	12	40	6	272–302	» 60
40KhS	910 930	Oil	600 650	Water	90	70	12	45	6	246–289	» 60
30KhNZ	820 840	Oil	520 550	Air	90	70	8	45	6	255	» 60
37KhNZA	810 830	Oil	550 590	Oil	110	100	10	50	7	330–418	» 60
40KhN	820	Oil	600	Water or oil	85	65	13	45	8	230–260	» 100
40KhN	840 820 840	Oil	650 500 560	The same	90	68	10	40	7	255	» 100
45R	840	Water	500	Air	100	80	14	50	8	—	—
40KhNMA	830 850	Oil	600 620	Water or oil	110	80	12	46	8	302	До 50
35KhM	850 870	Water or oil	600 640	water	70	50	15	45	6	235	» 100
35KhMFA	840 860	The same	600 620	Air	100	90	15	55	8	262	» 50
40KhG	860 880	oil	550 600	Water	100	80	10	45	6	272–302	» 60

* limits of temperatures are shown.

steels, cooling with isothermal hardening in a medium having a temperature higher than 400°, leads to a lowering of values of shock viscosity (Table 11).

Table 11. Shock Viscosity and Hardness of Steel After Isothermal and Common Hardening with Tempering [1]

Brand of steel	Isothermal hardening			Common hardening with tempering		
	Temperature of tempering medium in °C	a_H in kg·m/cm²	HRC	Temperature of tempering in °C	a_H in kg·m/cm²	HRC
30KhGSA	325 370 400 425 450	11.5 11.3 10.5 4.8 4.5	48 45 37 35 35	250 300 350 400 450 500 550	5.2 4.8 4.5 4.0 5.5 7.5 8.0	52 52 50 45 43 40 35
38KhA	300 350 400 450	6.8 7.0 7.0 4.0	48 42 35 32	200 300 400 500 550	6.0 4.0 4.5 7.5 12.0	52 47 45 38 35
40KhNMA	300 325 375 400 450	6.0 6.5 6.5 6.5 3.5	48 — 40 37 33	200 300 350 400 500	3.8 1.8 2.0 4.0 7.5	53 47 — 45 38

A variety of isothermal hardening is light isothermal hardening,* which is applied for thin-walled flat articles and articles of small cross-section (disks, rings, springs, bolts, shafts, bushings, parts for fuel equipment and others), prepared from steel brands 85, 65G, 35KhGS, 60S2A, 37KhS, 50KhFA, and also for tools. As a result of

*This method was developed by Wolf and Garden.

light isothermal hardening, in contrast with common isothermal hardening, articles are obtained pure and light and do not require subsequent purification.

Step hardening consists of heating steel to a temperature above AC_3 by 30-50°C, holding at this temperature, cooling in a medium having a temperature 20-40°C higher than the temperature of the beginning of martensite transformation M_H holding at this temperature in order to equalize it all over its section and, finally, cooling in air or in another cooling medium (Fig. 1, III). Thus a martensite structure is obtained.

Step hardening is used for details of complicated configuration (for instance, gears), prepared from alloy and carbon steel (and also for tools) having a requirement of minimum deformation.

The required mechanical properties are obtained after corresponding tempering.

The cooling of steel for different types of hardening occurs in the following manner.

During common hardening in water (Fig. 1, I), when the temperature of the surface of a steel article, during cooling, attains the temperature of the beginning of martensite transition M_H (point H), the temperature of the core (point a) is still very high.

When the formation of martensite is already completed in the surface layer of an article (point K), it has still not started in the core (point b). The formation of martensite in the surface layer, possessing a large specific volume, evokes significant stresses and their resultant deformation. The martensite transformation in core starts at point M_H, the temperature of the surface is close to the temperature of the tempering medium which also causes the appearance of stresses.

When hardening in oil (Fig. 1, II), the cooling of the surface and core occurs, thanks to a smaller speed of cooling, with a significantly smaller difference in temperatures (straight line Ha > H_1в; Kв > K_1г), which leads to the formation of residual stresses of significantly smaller value.

During step hardening (Fig. 1, III) temperature M_H + (20 to 40°C) throughout the section of steel detail is equalized to the beginning of martensite transformation (at point M_H); therefore the difference between temperatures of the surface and the core of article at the moment of the beginning of martensite transformation is very small and the stresses obtained are extraordinarily small. The lag of the cooling of the core of a detail behind the cooling of its surface, during hardening in water may be seen from the curves in Fig. 2.

For cooling during common hardening, depending upon the brand of steel, different coolers are utilized. For hardening, the speed of cooling in two temperature intervals (Table 12) 650-450°C (zone of least stability of austenite) and 300-200°C (zone of martensite transformation) is basic, whereby in the first interval a rapid speed of cooling (not lower than critical, equal to 150-500°C/sec) to avoid the transformation of austenite in a ferrite-cement mixture, but, in the second interval a 10-20°C/sec is required to avoid the appearance of significant stresses and their resultant deformations and tempering cracks.

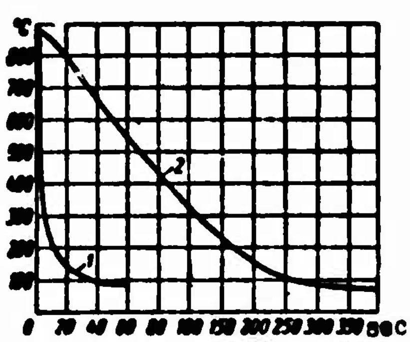

Fig. 2. Curves of cooling of a steel sample (50 × × 150 × 200 mm) from temperature of 880° in water (20°); 1 - surface of the sample; 2 - center of the sample.

For cooling steel during isothermal and step hardening hot oils (150-230°C) are applied (steam engine cylinder oil, cylinder 6) and

melted nitric- and nitrous acid salts of sodium and potasium — saltpeter $NaNO_3$ and KNO_3 and nitric-acid salt $NaNO_2$ and KNO_2.

Table 12. Speeds of Cooling Steel in Different Hardening Media (S. S. Shteynberg)

Hardening medium	Speed of cooling in °C/sec in an interval of temperatures in °C	
	650-550	300-200
Water at 18°C............	600	270
Water at 26°C............	500	270
Water at 50°C............	100	170
Water at 74°C............	30	200
A 10% water solution NaOH*..................	1200	300
The same NaCl*...........	1100	300
The same Na_2CO_3*.........	800	270
The same H_2SO_4...........	750	300
Saponaceous water........	30	200
Mineral oil..............	100-120	20-50
Emulsion of oil in water.	70	200
Transformer oil..........	120	25
Machine oil..............	100	18-15

*Temperature 18°C.

Hot oils, because of their hardening ability, almost do not differ from the oil applied for common hardening at a temperature 30-70°C (Table 13). The hardening ability of salt bath solutions is sufficiently great, but with an increase in the temperature of the bath it drops. Comparative speeds of cooling, during hardening steel, in water, saltpeter and oil are shown in Fig. 3.

Table 13. The Speed of Cooling Steel 20 at 845°C (Sample having a Diameter of 22.2 mm)

Type of hardening	Temperature of tempering oil in °C	Duration of cooling in seconds to a temperature in °C			
		700	540	370	200
Common	30	9.1	14.6	22.5	37.5
	40	9	13.2	20.2	36.3
	60	8.5	13.5	21.2	38.5
Step	120	7.3	13.5	24.5	53.8
	150	6	12.5	26	64
	180	6.3	13.0	26	84
	200	6.3	13.3	24.8	–
	230	6.3	13.0	28.7	–

During light isothermal hardening, alkali salts KOH, NaOH and their mixture are applied as a tempering medium.

For a increase in the intensity of cooling details during hardening, a mixing of the hardening medium by ultrasonics is applied (Table 14). In this way a high and isometric surface hardness, and also the quantity of cinder and tempering oil on details after hardening decreases sharply (Table 15).

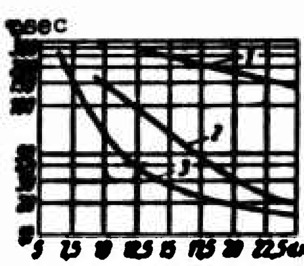

Fig. 3. Speed of cooling from temperature 705° in the center of samples of different diameter d of steel 50, depending upon the type of cooling medium: 1) circulating water at 8° (holding samples until complete cooling); 2) mixed saltpeter at 175° (holding of samples for 30 sec); 3) circulating oil at 55° (holding of samples until complete cooling).

Surface hardening is heating, at great speed, the surface layer of a steel detail to a temperature higher than the interval of transformations and subsequent rapid cooling to obtain a definite depth of martensite structure in the hardened surface layer. This is used for machine parts (and tools) for the purpose of obtaining a high hardness and durability of the surface layer, a high resistance to wear and increase of fatigue and contact

durability. With surface hardening, the deformation of detail (in comparison with deformations during volume hardening), and also sensitivity to concentration of stresses (hollows, hole, groove, silts, and so forth) decreases.

Table 14. The Intensity of Cooling Steel in Different Tempering Media (Relative Units)

Tempering medium	Calm liquid	Liquid, mixed mechanically	Liquid, mixed by ultrasonics (frequency, 20 kilocycle)
Oil................	1	2.7-3.6	5.5
Solution of salt at 20°...........	1	2.5	3.7
Solution of salt at 200°..........	1	4.3	6.0

Table 15. The Influence of Ultrasonic Oscillations in an Oil Bath while Hardening Carbon Steel (C = 1.0%) from Temperature 845° (Samples ϕ 25 mm; h = 25 mm)

Parameters	Mineral oil	
	Calm	Mixed ultrasonic oscillations
Surface hardness HRC........	29-38	48-50
Quantity of cinder, remaining on the samples after hardening in oil, in %.....	100	10-40
Quantity of oil, remaining on the samples after hardening in oil, in %.....	100	50

Table 16. Characteristics of Methods of Surface Hardening

Heating		Cooling	Depth of hardened layer in mm	Deficiencies of methods	Applicability of methods
Method	Characteristics				
Volume heating and surface cooling	Volume (continuous) heating in furnaces to a temperature of AC_3 + 30-50°C	In a sharply hardening 3-7% water solution NaOH at a temperature of 25-35°C; holding for 5-50 sec	To 5	Difficulty of obtaining a stable depth of hardened layer, necessity of applying tempering machines by rotating the details during their hardening in a pressed state	Limited application of revolution (crankshafts, camshafts, axles and others) for bodies
Surface heating in lead baths	Volume (continuous) heating in furnaces to a temperature lower than AC_3 with subsequent fast surface heating in a lead bath, overheated significantly higher than the temperature AC_3	In water or oil	1-2	Necessity of the presence of two thermal units for preheating and heating details; deficiency of lead; evaporation and oxidation of lead with a high temperature of bath (to 950°C) and loss of lead while removing with details; difficulty of obtaining a stable depth of hardened layer	Highly limited (for gears, shafts, of small cross-section and so forth of details of steel with a lowered annealing capacity)
Electro-heating in electrolyte (Yasnogorod method)	Surface heating in electrolyte (water of 5-10% solution Na_2CO_3 or other salts) with a direct current of 200-250 volts, from 2 to 20 a (density of current 3-7 a/cm²), temperature of the electrolyte 20-60°C	In the same electrolyte after disconnecting the current or in a tank with water or oil	1.5-5	Difficulty of control and adjustment of temperatures and possible resultant obtaining of overheating of the hardened layer	Limited (for details of simple configuration — shafts, cams, axles and others)
Contact electro-heating (Geveling method)	Surface heating with heat, separated during contact electro-heating alternating current 50 cycles, 2-8 volts, electrode — copper rollers, which roll along the surface of the detail at a speed of 2-10 mm/sec (actually 3-6 mm/sec)	With the help of a spraying device by water or with an internal unheated part of metal (core)	1.5-6	Small productivity; obtaining an unclean (dented) surface, presence of annealing line	Very limited (for shafts, axles, spindles of heavy-gage)
Heating with gas-oxygen flame	Surface heating with the help of burner (acetylene, illumination gas, generating gas, vapor of kerosene and others are applied as fuel) Basic methods of hardening are analogous to high-frequency hardening	With the help of a spraying device by water	To 6	Difficulty with control and adjustment of temperatures and possible resultant obtaining of overheating of the hardened layer	Wide (for teeth of big gears, necks of shafts and heavy-gage axles, operating planes of big details and others)
Electro-heating (Vologdin method)	Induction surface heating using inductors Basic methods of hardening: a) simultaneous heating and hardening of the processed surface (for small surfaces) with a motionless detail or while it is rotating; b) continuous-consecutive heating and hardening of a processed surface (teeth of big gears, shafts, axles, driving machines and others) with a shift of the inductor in relation to the detail or the detail to the inductor; c) consecutive heating and hardening of separate parts of the detail (teeth of large gears, necks of large shafts).	With the help of a spraying device by water, emulsion, water — air mixture or submersion in a tank with oil	0.3-8	—	Very wide for different details in machine building (big, average and small gears, axles, shafts, planks, drivers, spindles, shafts, running machine screws, stopper stable rings, bolt head, muff cams, bushings, rings, nuts, rotors of hydraulic pumps and others)

Heating is carried out (Table 16) by means of electrical power (induction heating by currents of industrial, heightened or high frequency; contact heating; heating in electrolyte), gas oxygen flame (acetylene, illumination gas, natural gas and others) or by means of preliminary preheating of details (in furnaces, baths) to a temperature lower than Ac_3 with subsequent fast heating in a lead bath, having a temperature significantly above Ac_3; furthermore the detail is heated to a required temperature to a definite depth from the surface (0.5-1.2 mm) and is subjected to hardening.

Methods of surface hardening with electro-heating and particularly by gas-oxygen flame have been most widespread.

Cooling during surface hardening with electro-heating or gas-oxygen flame is most frequently carried out with the help of showering devices with the application of water, water — air mixture or emulsion as a liquid coolant. Oil, because of its coking in the holes of the spraying device is not applied for this purpose.

Necks and hollows of crankshafts, neck and cams of camshafts, cases of cylinders, piston pins of internal-combustion engines, teeth of gears, shafts, spindles and directrixes of machines, pins of track and other details, prepared mainly from carbonic and low-alloy steels of brands 40, 45, 50, 40Kh, 40KhN, 45Kh, 40G, 50G are subjected to surface hardening.

With a selection of a method of surface hardening of details it is necessary to consider the following:

a) the possibility of applying a method of hardening for a detail of given configuration and dimensions, taking into account concentrators of stresses; such as for details of very complicated configuration, requiring surface hardening by contour, hardening with high-frequency heating extraordinarily is complicated, is impractical

and frequently turns out to be impossible; in these cases one of the processes of chemical heat treatment is applied, depending upon the conditions of operation of the details and the requirements made of them (magnitude and character of stresses, resistance to wear, presence of impact loads and so forth);

b) obtaining the required high durability characteristics (HB, σ_B, σ_T, σ_1) viscosity (σ_H), plasticity (δ, ψ) and resistance to wear;

c) providing a minimum of deformations during heat treatment;

d) obtaining maximum technical-economic efficiency of the selected method of hardening.

The magnitude and character of surface hardening of steel details depend on properties of the hardened layer and core, and also on the magnitude and distribution of residual stresses in the hardened layer and in its directly adjoining underlayer.

Surface hardening with electro-heating, in comparison with other methods, possesses significant advantages, the basic of which are a lowering of primecost and a sharp decrease of duration of heat treatment, a decrease of deformations during heat treatment, the obtaining of parts with a clean cinderless surface after hardening, possibility of mechanizing and automating the process of hardening and the inclusion of tempering assembles in production lines for machining details.

Electro-heating is based on the following: during transmission through conductor-inductor an alternating magnetic field* is created around it; an induced (vortex) current is activated in processed detail,

*Actually from 10^3 to 10^4 gps with machine generators and from 150.10^3 to 100.10^4 cps with vacuum-tube oscillators.

placed inside inductor, which causes a heating of the detail. The induced current is concentrated in the surface layer of the detail, and the higher the frequency of the current, the less the depth of its penetration.

With high-frequency heating, heat appears in the detail itself, which allows the obtaining of very high speeds of surface heating to the required temperatures of hardening, which exceed point Ac_3 by 50-120°C; a detail heated thus is cooled by water or other cooler, as a result of which there occurs a hardening of surface layer to a definite depth.

Basic factors, determining the depth and quality of the hardened layer at a selected frequency and density of current, are the temperature and speed of heating; the less the speed of heating and the higher its temperature, the greater the depth of the hardened layer.

Steel details, hardened with electro-heating (in comparison with steel, tempered in furnace), have increased their Rockwell hardness by 2-4 units, possess a higher resistance to wear and a durability and produce significantly smaller deformations.

After the high-frequency hardening there follows a low tempering which is frequently replaced by self-tempering which is carried out with heat, kept in the detail by stopping its cooling.

With the use of high-frequency heating for surface hardening of details it is necessary to consider the following:

a) with increase in the depth of hardened layer (relation of the depth of layer to the section of the detail) the limits of strength at first is increased, attains a maximum value, and then decreases.

For instance, during a test of samples with a diameter of 7.5 mm, and a length of 100 mm having a cut (steel 45) for an alternating bend

(console), the following results were obtained (data from Karelin and Mirolubov):

Depth of hardened layer in mm	Limit of strength in kg/mm^2
0.5	40
1.0	44
2.0	38
4.0	18

b) fatigue destruction of details, subjected to local surface hardening and working in conditions of alternating loads, occurs in that place, where the hardened layer is finished, especially if a sharp cut of hardened layer spreads to places of stress concentration (for instance, hardened neck of a crankshaft with a nonhardened hollow); this leads to a decrease of resistance to fatigue, which is result of the fact that in part of the nonhardened surface, adjoining directly to the strengthened part, stretching stresses of significant amounts are formed. Surface strength during hardening with electro-heating has the influence of stress concentration removed (Table 17).

Necessity of applying carbon (0.35-0.60%) for surface hardening of steel with average content for providing a high surface hardness is seen in the curve in Fig. 4. A schematic distribution of hardness by section of surface hardened layer of steel 40 is shown in Fig. 5.

Surface hardening by heating with a gas-oxygen flame, as a simple and accessible method, not requiring expensive installations, has found wide application, especially for big steel details.

Table 17. The Dependence of a Limit of Strength of Steel 40KhNMA on the Form of Surface Hardening with Electro-Heating of Shafts with a Diameter of 40 mm. (Preliminary Hardening at 850° and Tempering at 550°) [12]

Presence of concentrators of stresses	Electro-hardening	Limit of strength in kg/mm^2
Without concentrators of stresses	Without hardening	48
Circular hollow	The same	24
Without concentrators of stresses	Surface hardening of shaft by electro-heating $\frac{\Delta}{g} = 0.25$ HB630-640	56
Circular hollow	The same. The hollow is hardened on the surface	56
The same	Surface hardening of shaft by electro-heating $\frac{\Delta}{g} = 0.25$ with a break off of layer at the beginning of the hollow. Hollow is not hardened on the surface	16

Tempering — the process of heat treatment of preliminarily hardened steels, which causes more equilibrium of structures. Unbalanced structures of hardening — austenite and martensite — give, in accordance with the temperature of tempering, more equilibrium structures — martensite of tempering, troosto-martensite, troostite, troostosorbite, sorbite.

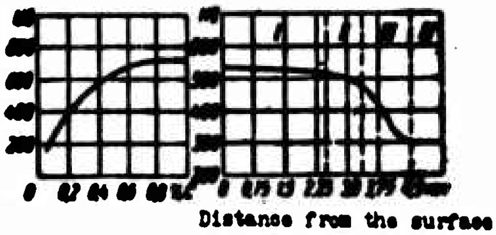

Fig. 4. Fig. 5.

Fig. 4. Influence of the content of carbon in carbon steel on surface hardness after gas-oxygen hardening.

Fig. 5. Hardness after surface hardening: I — martensite (hardened zone); II — troostomartensite (transition zone); III — troosite (transition zone); IV — perlite and ferrite (core).

Tempering is applied after hardening (normalization) the steel castings, forgings, rolling and mechanically treated details and is carried out by means of heating the steel to a temperature lower than the interval of transformations, holding and subsequent cooling. The purpose of tempering is to increase the cohesive properties, decrease of internal stresses and fragility, and improve the workability while cutting.

The process of tempering is subdivided into high, average, and low according to temperature of heating.

High tempering is heating hardened steels to a temperature higher than 500°C, but lower than Ac_1 (usually in the interval of 500-670°C), holding at this temperature and cooling at the required speed. Delayed cooling of chromous, manganic, chrome-manganese, siliconmanganic, chrome-nickel, chromosilicon steel (and steel with a content of $P > 0.1\%$) with high tempering leads to a sharp lowering of shock viscosity, since these steels are inclined to tempering fragility.

An increase in the speed of cooling (in water instead of cooling with a furnace) significantly increases the magnitude of shock viscosity.

The purpose of high tempering is the maximum increase of plastic and viscous properties during a certain lowering (but with a preservation of sufficiently high values) of hardness, ultimate strength and fluidity (with extension) and internal stresses are

decreased.

This form of tempering is applied mainly for carbonic and alloy improved steels, the mechanical properties of which, obtained after improvement (hardening and high-temperature tempering), are given in Table 10.

As a result of high tempering of hardened constructional steels a sorbite microstructure is obtained.

Average tempering is heating hardened steels to a temperature in the interval of 250-450°C, holding at this temperature and cooling.

The purpose of this tempering leave is to decrease the internal stresses and to obtain a heightening of plastic properties with higher values of hardness, ultimate strength and fluidity than with high tempering. This is applied mainly for spring details (springs, leaf spring, shafts of rod).

Low tempering is heating of preliminarily hardened steels to a temperature in the interval of 140-230°C, holding at this temperature and cooling of any speed for the purpose of decreasing the internal stresses and preserving high values of hardness, ultimate strength and fluidity with lowered values of viscosity. As a result of tempering a microstructure of the initial stage of disintegration of austenite and martensite of tempering is obtained. This is applied after the hardening of mainly cemented, cyanic surface hardened and volumetrically hardened details with requirement of high surface and resistance to wear (and also for tools of carbonic and alloy steels).

The dependence of hardness on the temperature of tempering for carbonic and alloy steels of different brands is given in Table 18.

Table 18. Temperature of Hardening and Tempering, and also the Obtained Hardness for Steels of Certain Brands

Brand of steel	Hardening				Tempering		Hardness		
	with heating to a temperature in °C (after cementation)	direct after cyanidation at a temperature °C	volume at a temperature °C	Cooling medium	Temperature in °C	Cooling medium	core HB	core HRC	surface HRC
10 & 15	780–820 –	– 820–[illegible]	– –	Water	170–200 160–200	– –	– –	< 30 < 30	> 56 > 56
20	780–810 –	– 820–850	– –	Water	170–200 160–200	– –	– –	< 30 < 30	> 56 > 56
[illegible]	– –	810–[illegible] –	[illegible]	Water	180–200 220–300	– –	– 282–363	– –	> 56 –
40	–	–	[illegible]*	Oil*	550–600 400–420	– –	– –	25–30 35–43	– –
	–	–	820–840	Water	650–660 280–320 300–400 400–460 510–550 540–580 590–640 660–680	– – – – – – – –	– 375–477 364–444 321–415 241–285 228–269 192–228 167–228	24–28 – – – – – – –	– – – – – – – –
45	–	–	[illegible]*	Oil*	400–[illegible] 630–[illegible]	– –	– –	39–42 18–26	– –
	–	–	810–840	Water	200–240 420–460 480–500 510–550 540–580 600–630	– – – – – –	444–515 302–363 [illegible]–321 [illegible]–302 [illegible]–285 217–263	– – – – – –	– – – – – –
	–	–	840–850*	Oil*	290–310	–	–	48–52	–
50	–	–	810–830	Water	450 550 650	– – –	~ [illegible] ~ 248 ~ 228	– – –	– – –
[illegible]	–	–	[illegible]*	Oil*	300–310 340–[illegible] 400–[illegible] [illegible] [illegible]	– – – – –	– – – – –	50–55 47–53 34–40 30–43 26–31	– – – – –
20G	780–810	–	–	Water	180–200	–	–	–	56–62

* For details of small cross-section

Table 18 (Continued)

Brand of steel	Hardening				Tempering		Hardness		
	with heating to a temperature in °C (after cementation)	direct after cyanidation at a temperature in °C	volume at a temperature in °C	Cooling medium	Temperature in °C	Cooling medium	core HB	core HRC	Surface HRC
50G	–	–	810–840	Oil	180–200 380–440 560–600	– – –	– – –	> 50 40–48 24–30	– – –
			830–850 *	Water*	550–600	–	241–286	–	–
60G	–	–	800–820	Oil	420–470 480–530 560–600 650–680	– – – –	311–401 269–321 241–255 179–229	– – – –	– – – –
65G	–	–	790–810	Oil	300–350 370–410 420–450 510–530	– – – –	– – – –	48–54 40–50 38–45 36–44	– – – –
55S2	–	–	900–940	Oil	600–620 400–450	– –	363–415 –	– 43–48	– –
20Kh	800–830	–	–	Oil	180–200	–	–	20–32	57–63
40Kh	–	820–830	–	Oil	180–200	–	–	–	48–56
	–	–	820–830	Water	580–600	Вода	~ 302	–	–
	–	–	840–860	Oil	180–200 350–400 550–600 600–650	Вода	– – 341–415 269–302	46–53 35–40 – –	– – – –
45Kh	–	–	830–850	Oil	480–490 580–620 600–650	Вода	302–341 255–285 > 241	– – –	– – –
50KhFA	–	–	850–870	Oil	430–450	–	–	40–47	–
35KhM	–	–	820–860	Oil	180–200 580–620	– –	– 241–285	48–56 –	– –
18KhGT	830–850 (after super-cooling)	–	–	Oil	200–220	–	432–375	–	56–62

• For details in section of more than 80 mm.

Table 18 (Continued)

Brand of steel	Hardening				Tempering		Hardness		
	with heating to a temperature in °C (after cementation)	direct after cyanidation at a temperature in °C	volume at a temperature °C	Cooling medium	Temperature in °C	Cooling medium	core HB	core HRC	Surface HRC
20KhN	790–820	–	–	Oil	180–200	–	–	–	56–62
40KhN	–	–	820–840	Oil	550–600 600–650	– –	255–296 230–260	– –	– –
	–	810–830	–	Oil	190–200	–	–	–	60–64
12Kh2N4A 20Kh2N4A	790–810	–	–	Oil	160–180	–	–	35–48	> 58
37KhS (40SKh)	–	–	880–900	Oil	290–320 430–470 580–620 630–680	Вода	–	47–53 38–43 33–37 20–30	– – – –
35KhGS	–	–	870–890	Oil	200–250 270–290 520–540 640–660	Вода	– 441–555 321–398 > 235	46–53 – – –	– – – –
12KhN3	770–800	–	–	Oil	180–200	–	–	26–46	56–62
37KhN3A	–	–	820–840	Oil	200–220 525–575	– –	– 321–387	46–52 35–40	– –
18Kh2N4VA	780–810	–	–	Oil	160–170	–	–	35–47	> 56
	–	–	850–870	Oil or air	180–200	–	311–387	–	–
			850–870	Oil	550–580	–	241–285	–	–
NMFA	–	–	860–880	Oil	390–420 460–480 550–600 600–650	– – – –	415–477 388–444 321–363 260–321	– – – –	– – – –
ShKh12 ShKh15			830–865 860–870 •	Oil kerosene	160–180 180–220 160–170	– – –	– – –	61–65 59–63 61–65	– – –

• For smoked details

Reference book of machine builder, Vol. 5

Aging is the process of heat treatment, intended for accelerating the completion of transformations in steel and stabilizing the dimensions of articles. Aging consists in heating hardened articles to 150-180°C and holding at this temperature for 5-25 hours. Aging is used for measuring tools and exact details (needle of atomizer, plunger, bushing and other details of diesel fuel equipment and so forth).

Treatment at a temperature lower than zero is a process of heat treatment of preliminarily hardened steels, intended for the most fully transformed residual austenite in martensite for the purpose of increasing the hardness and resistance to wear of details, the stability of cutting tools, and also the stabilization of dimensions of exact articles.

This process is applied for details of high-alloy steel (for instance, 12Kh2N4A, 20Kh2N4A, 18Kh2N4VA) after cementation and hardening, since there is a residual austenite in hardened carburized layer, lowering the resistance to wear and the fatigue durability of details, and also for tools, prepared from steel brands R9 and R18.

Hardened articles are held in medium with a temperature from -70° to -150°C and are naturally heated in air to a normal temperature.

For instance, in obtaining, after the cementation and hardening of steel 18Kh2N4VA, a surface hardness of HRC 53 the treatment by cold increases the hardness to HRC 62; for steel 20Kh2N4A the hardness is increased from HRC 58 to HRC 64 and for steel 12KhN3 — from HRC 60 to HRC 63-64.

Chemical-heat treatment of steel. During chemical-heat treatment the chemical composition of surface layers is altered, ensuring the improvement of mechanical, physical and physical chemistry properties

(durability, resistance to wear, heat resistance, fatigue durability). This increases the utilization quality and extends the period of service of details.

Treatment in an atmosphere of steam. Treatment by steam is applied mainly for tools of high-speed cutting steels of brands R18 and R9 and is conducted after hardening. It is combined with tempering at a temperature of 560-570° or after finishing grinding at 540-560°. Moreover, on surface of tools will be formed an oxidized film Fe_3O_4, protecting the tool from shaving remains, increasing its stability on the average of 25-30% and its corrosional stability. The thickness of oxidized film on steels of brands R18 and R9 after treatment by steam constitutes 2-6 μ; the porous surface of oxidized film retains the lubricant and liquid coolant. Treatment in an atmosphere of vapor at 500-550°C to obtain a thin oxidized film of brilliant metallic form is applied also for details of constructional steel for the purpose of protecting their surface from decarbonizing and oxidation during subsequent heating for hardening at temperatures of 780-850°.

Cementation (carburization) is a process of chemical-heat treatment, which causes a saturation of the surface layer of carbon steels. As a result, after heat treatment (hardening and low tempering) of the carburized details, hardness and durability of surface layer (Table 19), resistance to wear and fatigue durability (Table 20) of the details is increased.

Table 19. Mechanical Properties of Carbonic and Alloy Steels after Cementation, Hardening and low Tempering

Brand of steel	Place of determination of indices	σ_B in kg/mm^2	σ_T in kg/mm^2	δ in %	ψ in %	HB
20	Carburized layer......	185-210	125-140	5-10	8-12	515-600
	Core.................	40-50	20-25	30-35	40-50	120-140
Nickel (0.10-0.20%C 3.25-3.75% Ni)	Carburized layer......	200-230	130-145	4-8	6-10	570-655
	Core.................	80-90	70-85	12-20	38-50	250-275

Table 20. Influence of Cemmentation on the Fatigue Limit of Steels (Sample with a Diameter of 14 mm)

Sample	Heat treatment	Fatigue limit in kg/mm^2	
		During bend	During torsion
Smooth	Volume hardening	62	25
The same	Cementation (depth of cemented layer 0.2 mm after grinding); hardening	70	31.5
With transverse hole 2 mm in diameter	Volume hardening	34	12
With transverse hole 2 mm in diameter, drilled before cementing	Cementation (depth of cemented layer 0.2 mm after grinding; hole cemented); hardening	44	29
The same, with hole drilled after cementing	The same, hole not cemented	21	10

Cementation consists of heating steel details to a temperature of usually 900-940°C in a carburizing medium, holding in this medium at the indicated temperature for a time, necessary for obtaining the required depth of carburized layer, and subsequent slow or fast (during direct hardening) cooling.

The results of cementation (depth of carburized layer, degree of saturation by its carbon, distribution of concentration of carbon by the depth of layer and the resulting distribution of hardness by the depth of layer after hardening) are influenced by (besides the form of process) the activity of the carburizer, the temperature and duration of the process. Furthermore the higher the temperature of the process and the longer its duration, the bigger the obtained depth of carburized layer.

An especially large influence on the depth of carburized layer is rendered by the temperature of the process that is used in practice for accelerating carburization (see curves 2 and 4 on Fig. 6).

Gears, piston pins, shafts of box of transmissions, distributor shafts, spindles of machines, levers, shafts, bushings and other details, prepared from carbonic and alloy steels with a content of carbon to 0.35% are subjected to cementation.

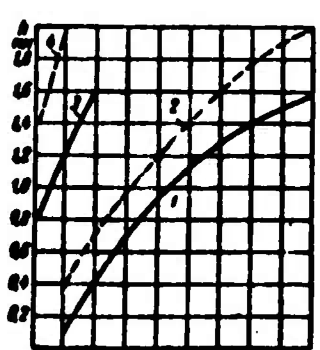

Fig. 6. Dependence of depth of carburized layer h on the general duration of the τ process of cementation: 1) hard carburizer, t = 930°; 2) gas, t = 940°; 3) liquid, t = 950°; 4) gas, t = 1100°.

Under the depth of cementated layer, indicated in TU, one should understand the part of layer, which, after hardening has a hardness is not lower than HRC 40-45 which corresponds to a semimartensite structure (content of carbon 0.40-0.50%). This part of layer effectively affects durability of

the detail and consists of sum of hypereutectoid, eutectoid and 2/3 transition zones.

Cementation with a hard carburizer is produced by means of heating steel details in a hard carburizer, consisting of a carbon containing substance (charcoal, napthane coke, peat coke), activators (salt $BaCO_3$, $NACO_3$) and binding (molasses, starch). During cementation the details are packed in an operating mixture, consisting of 15-30% fresh and 85-70% working carburizer.

Cementation with a hard carburizer possesses a series of deficiencies, among which are: formation of dust during packing and unpacking of boxes; difficulty in control of the depth of layer with the progress of the process; heightened labor-consumingness; increased duration of process of process (Fig. 6, curve 1) from unnecessary heating of the small-heat-conducting hard carburizer in boxes.

Liquid cementation is produced while heating steel details in a bath, consisting of a mixture of melted salts, including carburizing salts (most frequently NaCN or SiC), salt activator ($BACl_2$) and neutral salts (NaCl, Na_2CO_3).

The process of liquid cementation differs by its accelerated carburization (in baths with NaCN), uniformity of heating of details, ease of producing direct hardening (with super-cooling or without it) and reduction of deformations of cemented details (curves 3, Fig. 6).

Gas cementation is produced while heating steel details in gas medium, containing carburizing gases: methane CH_4, oxide of carbon CO, unlimited hydrocarbons C_nH_{2n}.

As carburizers for gas cementation, gases obtained by means of pyrolysis or pyrocracking kerosene; by disintegration of synthol, kerosene and in the operating volume of the furnace; endogas, obtained from natural or illumination gas (during incomplete burning) with

impurity of initial gas; and natural gas without processing are applied.

The basic advantages of gas cementation are analogous to the advantages of liquid cementation. The effectiveness of high-temperature gas cementation is illustrated by the curves 2 and 4 (Fig. 6), and also the data in Table 21.

Table 21. Influence of Temperature of Gas Cementation on the Depth of Cemented Layer (Cementation in Mine Furnace)

Temperature of cementation in °C	Depth of cemented layer in mm during the duration of process in hours		
	1	2	3
925	0.58	0.78	0.99
980	0.70	1.1	1.4
1035	0.95	1.5	1.98
1100	1.30	2.05	2.64

A significant influence is rendered on the fatigue and contact durability of cemented details by different factors, among which the most important are content of carbon in the surface zone of the carburized layer and content of austenite in the layer.

Optimum results on fatigue durability (resistance to wear and shock viscosity) are obtained with a content of carbon in the surface zone of 0.8-1.1%. With a content of carbon in this zone, for instance of 1.3%, there occurs a sharp lowering of fatigue durability (Table 22). Residual stresses of compressions, appearing in the cemented layer of details after hardening, significantly increase their fatigue durability.

An increase of content of carbon in the surface zone of cemented layer by more than 1.1%, besides appearance of carbides, promoting fragility (break-off, grinding cracks), lead to a formation of significant quantities of residual austenite in the cemented layer after hardening.

Table 22. Influence of Carbon Concentration in the Surface Zone of a Cemented Layer of Steel 20Kh on Fatigue Durability (after Cementing, Oil Hardening at 800°, Annealing at 180°) [4]

Total Depth of cemented layer, mm	Carbon concentration in surface zone, %	σ_{-1} kg/mm^2 (pure bending during rotation — base $6 \cdot 10^7$ cycles)
0.62	1.08	65
1.55	1.28	40
1.58	1.10	73

A heightened quantity of residual austenite is obtained also with a heightened temperature of hardening, direct hardening after cementation of high-alloy steels (for instance, steel 18Kh2NVA) and so forth.

Residual austenite acts negatively on fatigue durability (Fig. 7), reducing the magnitude of compression stresses. The presence of austenite in quantity to 25% changes the magnitude of residual stresses

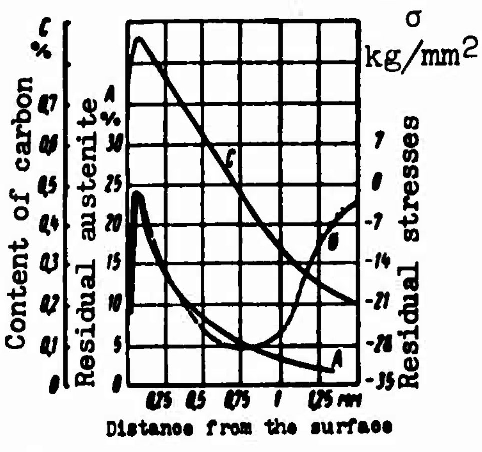

Fig. 7. Influence of a quantity of residual austenite in the cemented layer of gear teeth on the magnitude and distribution of residual stresses.

of compression from 28 kg/mm^2 to 0 (and even in stretching stresses) which lowers the fatigue durability of the gear teeth.

The action of residual stresses may be presented in the following form (Fig. 8): after cementation, hardening in oil, and low tempering, there appear in the gear teeth residual compression stresses $-\sigma$ of rather great magnitude in the zone of the start of cavities (Fig. 8a); in the core of the root of the tooth. Furthermore, there are

formed residual extension stresses $+\sigma$ of small magnitude, which do not present dangers for fatigue durability of the teeth. In an uncemented and nonhardened gear, load P causes equivalent stresses of extension (on the part of the action of a load) and compression (from opposite side of tooth, Fig. 8b) at the root of the teeth. In a cememted and hardened gear a similar load leads to the fact that the magnitude of extension stresses for the root of the tooth equals the difference of stresses (created by a load and the residual stresses after the indicated of the opposite side of the tooth (Fig. 8c).

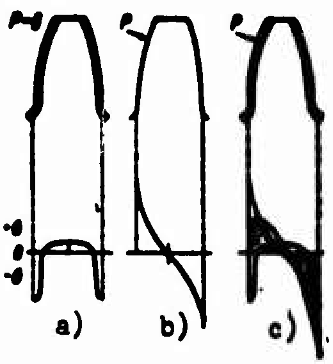

Fig. 8. Diagram of the formation and action of residual stresses in teeth of cemented gears from chromo-nickel steels [5].

<u>Nitrogen</u> is the process of chemical-heat treatment, causing a saturation of the surface layer of steel with nitrogen for the purpose of increasing its hardness (to HV 1150) and durability of surface layer, and increasing its resistance to wear, corrosional stability and fatigue durability of the detail.

Nitration is conducted in a medium, consisting of dissociating ammonia, at a temperature 490-570°C, with a heating of the detail to a required temperature, holding, depending upon the required depth of nitrated layer and slow cooling.

This is the most widely applied process of nitration (durability) for machine parts, working in conditions of friction and alternate bending loads (neck and crankshaft hollows of high speed motors, the operating mirror of cylinder cases, valve saddles, internal-combustion engine rods, gears, exact details of fuel equipment, spindles of high speed machines and so forth). Nitration is applied also to increase the resistance to wear of measuring tools (threading and smooth corks and rings, flat calibers, bracket, patterns and others).

For the manufacture of nitrated details steel brands 38KhMYuA, 35KhYuA, and also nickel chrome, nickel chrome tungsten, nickel chrome molybdenum, nickel chrome molybdenum and other constructional steels (18Kh2N4VA, 30KhN2MFA etc.) are applied most frequently.

The presence than aluminum in steels 38KhMYuA and 35KhYuA ensures the obtaining, after nitration, of maximum values of hardness (to HV 1150) and resistance to wear. Chromium increases the durability of nitrated articles and, furthermore, along with molybdenum, the heatedness of steel articles during their hardening before nitration.

The hardness of a nitrated layer steel brands 18Kh2N4VA and 30KhN2MFA is somewhat lower (to HV 900), and they have found application for nitrated details having a basic requirement, including an increase of fatigue durability.

Natural tests of crankshafts of high speed diesel engines for fatigue during bending showed that, in comparison with riveting of hollows, nitration gives higher values of durability (Table 23).

Table 23. Fatigue Durability of Crankshafts with Differently Treated Hollows [3]

Treatment of hollows of shaft	Stresses of symmetric cycle during pure bending	
	in kg/mm^2	in %
Grinding.............	10	100
Increase in radius of transition from necks to cheeks from 3.5 to 5 mm....	13	130
Rolling by ball, depth of riveted layer to 0.1 mm.....	13	130
The same, but depth of layer to 2 mm....	16	160
Nitration..........	19	190

Depending upon diameter of necks and radius of hollows durable nitriding of diesel crankshafts is produced to a depth of 0.3-0.5 mm.

With an increase of the temperature of the process the depth of nitrated layer is increased, but the surface hardness drops; with an increase of the duration of nitration the depth of nitrated layer; increases with an increase of the degree of dissociation of ammonia over 60% the depth of the layer decreases and the surface hardness drops (with a degree of dissociation of ammonia of over 60% the depth and hardness of the nitrated layer are practically not changed).

The process of nitration differs significantly in duration, and for the purpose its decrease are applied two-stage regimes are applied (I step – 500-510°; II – step – 550-575° or I step – 540°; II step – 570°; surface hardness HV 900-1000).

The influence of nitration on the increase of fatigue durability of steels is shown in Fig. 9.

A variety of this process is <u>anticorrosive nitration</u>, applied for small-loaded details, and prepared from carbonic and low-alloy steels.

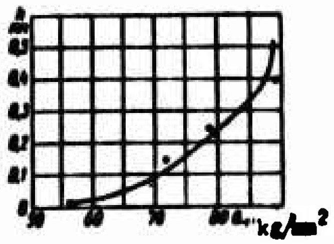

Fig. 9. Influence of the depth of a nitrated layer h on the fatigue limit of steel with flat bending (steel: 0.3% C; 2.5% Cr; 0.3% Mo; 0.25 V; samples 20 × 25 mm).

Moreover, in the surface layer there should be provided a maximum concentration of nitrogen.

Details, which are presented with the requirement of stability against corrosion, are subjected to nitration without subsequent hardening. For obtaining a higher durability, the details, after anticorrosive nitration, are subjected to hardening: low reliability (of steel U7, U10, ShKh12, ShKh15) from the temperature of nitration (without additional heating), more reliable with additional heating.

Carbon steel after nitration at 650°C for 3 hours or at 700°C for 0.5 hours does not corrode while immersed in water 720 hours.

Cyanidation is the process of chemical-heal treatment, causing the saturation of the surface layer steel simultaneously with carbon and nitrogen.

A cyanided detail, after hardening and low tempering, possesses more hardness and durability of surface layer, and fatigue durability (Table 24).

Table 24. Influence of the Depth of a Cyanided Layer on the Limit of Steel Strength

Brand of steel	Heat treatment	Depth of cyanide layer in mm	Limit of strength (bending during rotation) in kg/mm^2
10	Hardening	No	26
	Cyanidation and hardening	0.1 0.2 0.3	40 46 49
12KhN3	Hardening	No	41
	Cyanidation and hardening	0.1 0.15 0.25 0.35 0.50	45 47 50 55 63

Cyanidation is carried out by means of heating steel articles to 500-550°C, for tools of high-speed cutting steels or to 750-850°C for machine parts of constructional steels in a carburizing and nitrating medium, holding in this medium at the indicated temperature for a time, ensuring the required depth of layer, and subsequent slow cooling in air (for tools) or hardening (for machine parts). Depending

upon the assignment cyanidation is subdivided into low-temperature and high-temperature and is carried out with the application of hard, liquid or gasiform cyanide agent.

Low-temperature cyanidation in a hard medium is an imperfect process and in a few cases is used for tools* of high-speed cutting steels and consists of packing them in boxes with a cyanide agent (60-70% charcoal; 10-30 $NaCO_3$; 20-40% $K_4Fe(CN)_6$ or $K_3Fe(CN)_6$ and heating to 540-560°C, holding for 1.5-3.0 hours and subsequent cooling in boxes outside a furnace to 200-100°C.

Hardness of cyanided tools of steel R18 and R9HV is 1000-1100; the depth of a cyanided layer is 0.02-0.03 mm.

Liquid low-temperature cyanidation is used for tools (stretchers, drills, reamers, countersinks, taps, milling cutter) and consists in heating them in a melted mixture of salts, containing NaCN or $K_4Fe(CN)_6$, holding at a temperature 550-560° during the required time (from 5 to 35 min) and cooling in air. Surface hardness of tools, prepared for steel brands R9 and R18, after cyanidation is equal HV950-1100.

Liquid high-temperature cyanidation is used for details of machines (bolts, nut, screws, shafts, small gears of low- and average-carbon steel; gears, shafts, levers, strengthening and regulating bolts from average-carbonic alloy steels) and consists of heating details in cyanogen baths** to a temperature of 750-850°C, holding with this temperature (Fig. 10) and subsequent hardening in water (for instance, steel brands 15, 20, 25, 35, 40, 45) or in oil (for instance, steel brands 35Kh, 40Kh, 45Kh).

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*After their final thermal processing and machining.

**The active part of baths is NaCN (20-25%) or cyanide solution (7-10%), remaining neutral salts (Na_2CO_3 and NaCl – for a bath of NaCN and $BaCl_2$, $CaCl_2$,NaCl – for a bath with a cyanide solution).

A cyanided detail after hardening is subjected low-temperature tempering at 150-200°C. Surface hardness depends on the brand of steel, the temperature of the process and its duration.

Gas low-temperature cyanidation consists of heating tools of high-speed cutting steels to a temperature of 540-650°C in a carburizing and nitrating gas medium, holding for obtaining the required depth of layer and subsequent slow cooling.

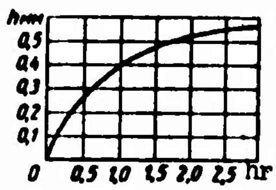


Fig. 10. Dependence of depth of cyanided layer h on duration of cyanidation of steel 15 at 850° in a bath with 30% NaCN.

Results of this process are analogous to those obtained during low-temperature liquid cyanidation.

Gas high-temperature cyanidation consists in heating details, prepared from carbonic and alloy cemented and improved steels in a medium, consisting of carburizing gas and nitrating ammonia, to 750-850°C, holding at this temperature for the time, necessary for obtaining a cyanided layer of required depth, and direct hardening of the steel. The influence of temperature and the duration of process on the obtained depth of cyanided layer is given in Table 25. This method of surface strengthening is used for loaded gears (automobile and tractor) box of transmissions and rear bridge, and also other details, where, besides an increase of resistance to wear and fatigue durability of gears, their deformation is minimum.

For an increase of saturation of a diffused layer of steel with nitrogen during cyaniding a gradual regime is applied. This leads to the following:

a) gas cementation at 925°, holding at this temperature for 4 hours with supply of carburizer;

b) lowering the temperature to 840°, holding at this temperature for 6-7 hours with a supply of carburizer and ammonia.

Table 25. Dependence of the Depth of a Cyanided Layer of Steel 20 on the Duration and Temperature of the Process (V. Chirikov)

Composition of gas	Temperature of process in °C	Length in hours	Depth of layer in mm
Natural gas 4 liter/min Ammonia 1 liter/min	860	1 3 4.5 6	0.33 0.40 0.60 0.70
Pyrobenzod 50-70 drops per minute	850	1.5 3 6 9	0.35 0.50 0.70 0.85
Ammonia 0.8-1.5 liter/min	750	1.5 3 6 9	0.20 0.30 0.40 0.50

As a result of carrying out the gradual conditions (4 + 6-7 hours) the depth of cyanided layer is 1.3-1.5 mm.

Sulfidation is the process of chemical-heat treatment, determining the formation of a surface layer on steel (and cast-iron) details, of saturated sulfur. This layer of chemical compounds plays the role of dry lubricant during friction.

The basic assignment of sulfiding is to increase the antiburr properties, easing and reduction of time of extra processing of rough surfaces, increase of resistance to wear and lowering the coefficient of friction (Table 26).

Sulfiding is conducted in a solution of salts, containing sulfurous joinings. With the presence in the bath of active cyanogen salts, the process is called sulfating and it gives (besides sulfur) a

saturation of the surface layer of steel with nitrogen (and carbon).

Table 26. Coefficient of Friction During the Shift of a Flat Surface about Spherical Abutment

Treatment of details of a pair	Coefficient of friction (in the absence of lubricant) a speed of cm/sec	
	0.003	0.004
Both surfaces not sulfided..........	0.76	0.82
Only the flat surface sulfided...	0.31-0.51	0.41-0.49
Both surfaces sulfided — flat and spherical......	0.17	0.15

Low-temperature sulfiding is intended for saturating with sulfur the surface of steel details, preliminarily hardened and subjected to low tempering while obtaining a high hardness (for instance, piston pins). The temperature of the process is 210-230° (does not have to exceed the temperature of low tempering). The active part of the bath is KCNS = 75% and $Na_2S_2O_3$ = 25%.

High-temperature sulfiding is intended for the saturation of preliminarily thermally untreated steel details or details, subjected to improvement.

The temperature of the process is 560-580°C. The process is conducted in a salt bath, containing neutral (for instance 55% Na_2SO_4 and 45% KCl) and active (NaCNS or KCNS — 2 weight part + $Na_2S_2O_3$ — 6 weight parts — bath NIIKhIMMAShA 2/6 No. 1) salt.

Steel shafts, bushing, gear, nut, plungers and plunger bushings, suction and groomed valve, cams and other details, working under average conditions of friction (Pv 70-120 kg/cm^{2}sec) in conditions of

limited and medium-dry friction* [6] are subjected to sulfiding.

Test of sulfided steels showed that for an increase of resistance to wear it is necessary to apply sulfating, i.e., simultaneous saturation S, N and C, whereby the surface film (15-30 μ), saturated with sulfur, plays the role of a dry lubricant, improves workability of details, prevents their burrs and snagging, but the underlying diffused layer, saturated by nitrogen and carbon, increases the resistance to wear of preliminarily processed surfaces of a friction pair.

Diffusion metallizing is the saturation of the surface layer of steel with aluminum, chromium, silicon, boron, and zinc for the purpose of giving the steel a high heat resistance, anticorrosive properties and resistance to wear. Characteristics for methods diffusion metallizing are given in Table 27.

Technological requirements. Constructive forms and relationship of sections of a detail should (with a given brand of steel) provide for obtaining the required exploitational properties without deformations of the detail during heat treatment, produced beyond the limits of permissible magnitudes, and without the formation of cracks. In this respect the most perfect are constructive forms of details, was not cut, acute angles and chisels, crossing of holes, hollows with a small radius of curvature and sharp transitions through the section of a detail which are concentrators of stresses during the hardening of details and leading to their deformation and formation of cracks, especially when hardening in sharp coolers (water, solution NaOH).

*Various cast-iron details, working in analogous conditions are also subjected to sulfiding.

Table 27. Characteristics of Processes of Diffusion Metallizing

Designation of method	Assignment of method	Application	Conducting of the process and obtained results				
			Temperature in °C	Medium	Heating of details	Obtained depth of layer δ in mm depending upon the duration of the process τ in hours	
						τ	δ
I. Calorizing* — saturation of the surface layer of steel with aluminum in a hard medium (in powder)	Heat resistance of steel details, working at a temperature up to 850-900°C	Cases of thermo steam, retorts for cyanidation, crucibles of salt baths, heating chambers of gas generators, cast-iron grates, steam superheated pipe, pipe for cracking of oil and exhaust and others	900	Mixture: 49% Al (powder); 49% Al_2O_3; 2% NH_4Cl	Detail are in a revolving retort with a calorizing mixture	t = 1000° 6	0.75
			1050-1070	or mixture: 35-50% Al; burned white clay 65-50% (powder)	Details are packed in boxes with a calorizing mixture	t = 1100° 12	0.7-1.0
Liquid	The same	The same	750-800	Bath with solutions of 92-94% Al; 6-8% Fe	Details are dipped in a bath	0.75-1.5	0.2-0.35
Gas	The same	The same	600 for one end of a retort and 900-1000 for the other	For the end of of a retort at t = 600°C placed in a mixture: 45% Al (powder); 45% Al_2O_3; 10% NH_4Cl. Through a retort hydrogen is passed (in the direction from the mixture to details), containing $AlCl_3$, which carries out calorizing	Details are located at the end of the retort	2-3	0.4-0.45

*After calorizing, the products are annealed at 900-1100°C

Table 27 (Continued)

Designation of method	Assignment of method	Application	Conducting of the process and obtained results				
			Temperature in ^{o}C	Medium	Heating of details	Obtained depth of layer δ in mm depending upon the duration of the process τ in hours	
						τ	δ
II. <u>Chromium-plating</u> — saturation of the surface layer of steel with chromium In a hard medium (in powder)	a) High resistance to wear b) Stability against gas corrosion (to $800^{o}C$) c) Anticorrosive stability in water and nitric acid	a) Details of precision machines b) Details of steam-powered equipment, valves, nozzles, and others c) Details of acid-resistant equipment d) Details, working on friction in an active medium	950-1050	Mixture: 50-60% Ferro-chrome (powder) 40-50% aluminum or kaolin; 2-3% NH_4Cl or 4-5% HCl	Details are packed in boxes with chromium mixture	t = $980^{o}C$ 1 2 4 6 t = $1050^{o}C$ 6 10 16	 0.03 0.05 0.08 0.10 0.13 0.16 0.25
Liquid	The same	The same	900-1000	Bath with a solution of 80% $BaCl_2$; 20% C Cl_2; 10-[illegible] $CrCl_2$	Details are submerged in a bath	t = 1000^{o} 2 4	Steel 45 0.06 0.12
Gas	The same	The same	950-1050	In an atmosphere of trenching chlorides of chromium ($CrCl_2$, $CrCl_3$)	—	3 5	0.06 0.10
III. <u>Siliconizing</u> — saturation of the surface layer of steel with silicon In a hard medium with a passing of gas chlorine	Increase of anticorrosive properties, resistance to wear and heat resistance of steel details (to $900^{o}C$)	a) Pistons for acid pumps and pumps for pumping solutions NaOH, valves, cocks b) Pipes for feeding sea water and others	1000-1100	Mixture: 100% ferro-silicon (or carbide silicon) 2% NH_4Cl; through a retort chlorine is passed; or 75% ferrosilicon, 20% fire clay, 5% NH_4Cl with a change of chlorine	Details are packed in retort with mixture	2 4	0.5 0.7

Table 27 (Continued)

Designation of method	Assignment of method	Application	Conducting of the process and obtained results				
			Temperature in °C	Medium	Heating of details	Obtained depth of layer δ in mm depending upon the duration of the process τ in hours	
						τ	δ
Gas	Increase of anti-corrosive properties, wear resistance of steel details (to 900°C)	b) Pipes for feeding sea water and others	[illegible]50-1100	The same, as in a hard medium, but the details are disposed in a separate retort; chlorine moves in both retorts	—	$t = 980°C$ 1 3 5 $t = 1100°C$ 1 2 3	 [illegible] 0.7 0.9 0.8 1.5 2.0
IV. **Borating** — saturation of the surface layer of steel with boron In a hard medium (in powder)	Increase of acid-resistance and heat resistance of steel details (to 800°C), and also wear resistance and hardness of carbonic and alloy steels	Tools, bushing, pins, shafts, cams	900-1000	Powder of ferroboron (content B = = 12-18%) 30-40% and alumina — 1-2%	Details are packed in boxes with powder of ferroboron and alumina	20-40	0.2-0.5
Liquid a) Electrolytic method	The same	The same	900-950	Bath with solutions ($Na_2B_4O_7$); density of current 0.1-0.2 a/cm²	Details (cathode) are dipped in a bath	$t = 900°C$ 3 5 8	 ~0.20 ~0.27 ~0.32
b) Solution	Increase of stability of cutting tools, prepared from carbon steels. Increase of acid-resistance and heat resistance (to 800°C), and also resistance to	Tools, bushing, pins, shafts, cams	900-950	Bath with solutions: 78% $BaCl_2$; 22% NaCl with an addition of 20% ferroboron or 10% carbide of boron (from the weight of salts)	Details are submerged in a bath	1 3 (bath with ferroboron $t = 9[illegible]0°C$) 1 3 (bath with carbide of boron, $t = [illegible]0°C$)	0.07 0.15 0.06 0.12

Table 27 (Continued)

Designation of method	Assignment of method	Application	Conducting of the process and obtained results: Temperature in °C	Medium	Heating of details	Obtained depth of layer δ in mm depending upon the duration of the process τ in hours: τ	δ
b) Solution (continued)	wear and hardness of carbonic and alloy steels						
V. Chromosilicating — saturation of the surface layer of steel with chromium and aluminum Gas	Significant increase of heat-resisting properties (chromo-silicated details possess higher heat resistance than chrome-plated or silicated)	The same for silicated or chrome-plated details, but working at a higher temperature. Cinder resistance to 1100-1200°C	950-1000	Passing HCl through the first retort with 45% Al, 45% Al_2O_3, 10% NH_4Cl at 600-650°C and passing HCl through a second retort with ferro-chrome and fire clay at 950-1000°C	Gas medium. Details are located in a separate retort, where gases are passed: from the first retort $AlCr_3$ and from second retort $CrCl_2$	t = 980°C 8 t = 1000°C 3	0.3-0.4 0.17
VI. Chromosiliconizing — saturation of the surface layer of steel with chromium and silicon gas	The same	The same. Cinder resistance to 1000°C	950-1000	Passing Cl_2 or HCl through a mixture of ferrosilicon and ferro-chrome (1:1), a mixture of gases $CrCl_2$ and $SiCl_4$ will be formed	Details are loaded in separate retorts, where a mixture of gases is directed	8 (Steel 30)	0.5

With an assignment of surface or local heat treatment during the development of constructive forms of details the possibility of the appearance of stresses of high value should be considered.

In designating a brand steel, besides the conditions of exploitation of the detail, it is necessary to consider also its maximum section and possibility of obtaining (with a given brand of steel) the required mechanical properties after heat treatment in the core.

For example, steel of brand 50 depending upon its section (from 20 to 200 mm) after hardening in water at 850°C and tempering at 580°C

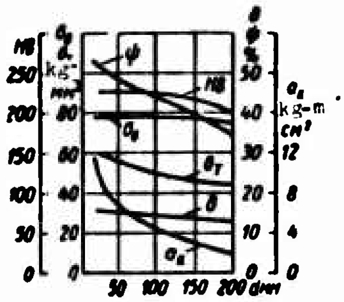


Fig. 11. Mechanical properties of steel 50 (central part) depending upon diameter d of blanks; hardening at 850° in water, tempering at 580°.

gives an oscillation σ_T of from 60 to 45 kg/mm^2, δ from 16 to 12%, ψ from 53 to 35%, a_H from 12 to 2 kg·m/cm^2 and HB from 225 to 200; σ_B furthermore, is changed insignificantly (Fig. 11).

Steel of brand 40Kh, depending upon its section (from 30 to 150 mm) after hardening in water at 850° and tempering at 580°, gives σ_B from 90 to 70 kg/mm^2, σ_T from 75 to 50 kg/mm^2, δ from 15 to 12%, ψ from 50 to 47% and HB from 293 to 200; besides this the shock viscosity a_H is not changed and is equal to 6 kg·m/cm^2.

<u>The hardening capacity of steel</u>. The ability of steel to accept hardening while obtaining a maximum hardness with a martensite structure is called the <u>hardenability of steel</u>. The hardenability of steel depends on the content of carbon in the steel (Fig. 12).

<u>Heatedness of steel</u>. Obtaining the required mechanical properties (definite relationship between high durability and sufficiently high

values of viscosity and plasticity of steel, Table 28) in the core (in the central part) of an article after heat treatment is associated with the heatedness of steel, i.e., with its ability to be hardened on definite depth. This characteristic of steel takes on an important meaning when using steels, especially for details of heavy gage.

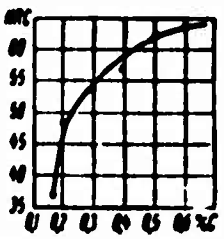


Fig. 12. Dependence of the surfame maximum hardness of hardened steels on their content of carbon.

Depth of heatedness is determined by the thickness of the hardened zone from surface to the layer with a semi martensite structure (50% martensite and 50% troostite).

Table 28. Plasticity and Viscosity of the Central Part of Forgings from Alloy Steels After Hardening and High-Temperature Tempering While Obtaining σ_B = = 85 kg/mm^2 (Sklyuyev)

Diameter of blank in mm	Hardening of steel																	
	30KhGS			40Kh						25N3			35KhM					
	In oil			In water			In oil			In water			In water			In oil		
	δ in %	ψ in %	a_k in kg-m/cm^2	δ in %	ψ in %	a_k in kg-m/cm^2	δ in %	ψ in %	a_k in kg-m/cm^2	δ in %	ψ in %	a_k in kg-m/cm^2	δ in %	ψ in %	a_k in kg-m/cm^2	δ in %	ψ in %	a_k in kg-m/cm^2
[illegible]	[illegible]	67	16	[illegible]	[illegible]	16	21	[illegible]	12	21	63	17	[illegible]	67	17	24	[illegible]	17
80	24	[illegible]	11	18	61	10	17	57	9	-	-	-	-	-	-	-	-	-
100	-	-	-	-	-	-	-	-	-	19	[illegible]	13	[illegible]	[illegible]	14	19	61	11
[illegible]	[illegible]	57	6	17	[illegible]	8	16	[illegible]	6	-	-	-	-	-	-	-	-	-
200	18	[illegible]	6	16	57	6	15	40	4	15	[illegible]	9	-	-	-	-	-	-

Heatedness of steel depends on its chemical composition (content of carbon and alloy elements), magnitude of grain, temperature of hardening, holding at this temperature before hardening and speed* of cooling during hardening.

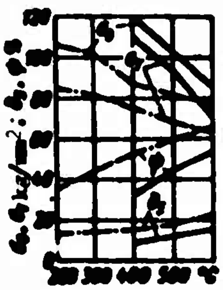
*Depending on the section of hardened article and type of hardening medium.

An increase of heatedness, thanks to elements placed in steel, is used for obtaining high values of mechanical properties in the central part of heavy-gage forgings (to 300 mm). If these forgings are prepared from low-alloy steels (40Kh), it is necessary to subject them to hardening with high-temperature tempering. Manufacture of such forgings from high-lay steels (for instance, 35KhNM, 35KhNZM) permits the application of the central part of forgings for normalization and high-temperature tempering instead of hardening and tempering to obtain high mechanical properties (σ_B, σ_s, δ, ψ, a_k). This is very important during heat treatment of details of complicated configuration and heavy-gage, since, besides a decrease of stress there are also deformations and a danger of obtaining of cracks.

An increase in the temperature of hardening increases heatedness steel.

A significant influence on heatedness is rendered by the speed of cooling during hardening. On Fig. 13 are given the mechanical properties of the central part of blanks with a diameter of 47 mm of steel 35Kh (0.34% C; 0.73% Mn; 0.95% Cr; grain No. 5), subjected to hardening in oil and in an 8% solution of NaOH (broken samples with a diameter of 20 mm were cut from the central part of details). The difference in mechanical properties after tempering at low temperatures (200-400°C) is particularly great after tempering at 600°C this difference significantly decreases.

Coarse-grained steel possesses significantly larger capacity for being tempered than fine-grained (Fig. 14) which is frequently used for obtaining high mechanical properties of the central part heavy-gage details.



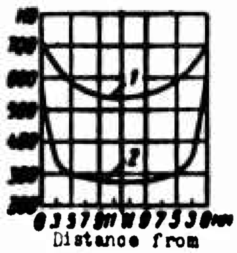


Fig. 13. Fig. 14.

Fig. 13. Mechanical properties of steel 35Kh after hardening in oil (dotted lines) and in an 8% solution of NaOH (solid lines) depending upon the temperature of tempering.

Fig. 14. Heatedness by the section of steel 40 (sample d = = 25 mm): 1 — coarse-grained (grain No. 3) 2 — fine-grained (grain No. 6-7).

In assigning a brand of steel and depth of cemented layer (with a given character and magnitude of loads), for cemented details, it is necessary to consider the ultimate strength of the core and carburized layer of steel, the relationship between the depth of carburized layer and the general section of detail. Furthermore the more durability of core of the steel after hardening and low-temperature tempering (see Table 9 and 16), the less will be (in known limits) depth of carburized layer.

An increase of durability of core of alloy steels may be attained by increasing in its content of carbon.

With a depth of cemented (or substantiated by other methods) layer which is too small for heavy-loaded details of heavey-gage, the layer of core, lying directly under substantiated layer, works at high tensions which requires high values of σ_B and σ_s. An increase in the depth of substantiated layer, in this case, increases the durability of detail. However, an oversized depth of substantiated layer, with the given section of detail, lowers its shock viscosity (Fig. 15).

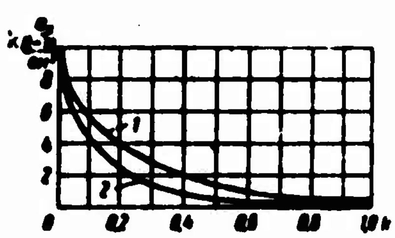


Fig. 15. Dependence of values of a_H on the relation of a cemented area in the operating section of F_1 to the general area of the section F; ($k = \frac{F_1}{F}$): 1) steel 12KhN3; 2) steel 0.14% C; 1.6% Ni.

In the case of small sections of detail and an excessively deep substantiated layer, while working in conditions of impact loads, the durability of detail can sharply drop which will lead to its destruction.

Deformation of steel during heat treatment. A deformation of details during heat treatment is understood as being a change in their volume and forms, which are caused by residual internal stresses; the magnitude and sign of these stresses determine the degree and character of deformations.

Irregularity of heating and cooling of details during heat treatment leads to a formation of thermal stresses; irregularity of structural transformations in time and according to the gage of a given detail, causes structural stresses.

The appearance of internal stresses and the obtained related deformations during heat treatment of steel details are influenced by the following factors: the degree of uniformity of heating and cooling, speed of cooling, heatedness of the steel, magnitude of the steel grain, temperature of hardening, temperature of tempering and others.

When heating steel details for heat treatment, their volume is increased in accordance with the temperature of heating and the coefficient of expansion. Uniform heating of steel detail, according to the gage, evenly increases its volume without the appearance of thermal stresses. With nonuniform heating (during high speeds of heating, when the surface of a detail attains high temperatures, but the core is heated to a lower temperature) an increase in volume by gage occurs nonuniformly, in consequence of which there appear internal stresses: in the surface layer there is compression stress, and in the core there is stress of extension. These stresses cause a deformation of detail.

The magnitude of deformations, obtained from these thermal stresses, is practically insignificant.

The temperature of hardening renders a significant influence on the degree of deformation of steel details. An increase in the temperature of hardening, leading to growth of austenite grain and resulting in tempering stresses, increases the deformation of steel details (Table 29 and 30).

Table 29. Change in the Length Initial Circumference of Gears of Steel 40Kh Depending Upon the Temperature of Hardening in Oil

Temperature of cyanidation and hardening in °C	Diameter of the initial circumference after hardening in mm	Increase of diameter in mm
Until hardening	90.246	0.000
760	90.302	0.056
805	90.310	0.064
815	90.325	0.079
830	90.340	0.094
845	90.348	0.102

Table 30. Change of Length of Cylindrical Samples (10 × 100 mm) Depending Upon the Temperature of Hardening in Water (Mochalkin)

Temperature of hardening in °C	Increase of length in %		
	Steel 18Kh2N4VA	Steel 38KhA	Steel 40KhNMA
800	0.25	0.22	0.20
850	0.32	0.30	0.25
900	0.40	0.40	0.32
950	0.45	0.48	0.40

A similar regularity of change in the dimensions of details, established by experimental means during hardening, allows the selection of an optimum temperature of hardening (ensuring the required

technological and exploitational properties) and the prior consideration of these changes during preliminary machining of details.

Cooling of steel details during hardening occurs nonuniformly. The surface layer of a detail is cooled with a higher speed than the core (and especially its central part), creating a large difference of temperatures between them. Due to this thermal stresses appear, which in surface the layers will be stretching, and in core will be compressing; this leads to a deformation of details.

An increase in the speed of cooling (during hardening in water in comparison with hardening in oil) the indicated difference of temperatures increases still more in the process of cooling with the appearance of large stresses and deformations of steel details.

Since the heating of details for hardening is carried out above point Ac_3, during cooling, besides thermal, there still appear structural stresses, related to the irregularity of structural transformations and the difference in volumes according to the gage of hardened detail.

During hardening in water the volume changes in the steel more than during hardening in oil which is explained by obtaining, during hardening in water, a tetragonal martensite, possessing a larger volume than martensite, which conditionally may be called martensite of tempering, obtained during hardening in oil, due to a lowered speed of cooling in the interval of martensite transformation. The combination of thermal and structural stresses leads to a decrease of deformations in those cases, when thermal and structural stresses have identical direction.

Thus, the speed of cooling during hardening renders a sharp influence on the formation of internal stresses and on the deformation of steel details. Thus, for instance, for gears, prepared from steel

brand 40, with a hole having a diameter of 54.63-54.67 mm, after hardening at 820°C in water, the latter is increased by 0.20-0.40 mm, and after hardening in oil (ensuring a much smaller speed of cooling) by 0.05-0.08 mm, i.e., 4-5 times less.

In Table 31 are given data, showing the influence of the nature of hardening medium (speed of cooling during hardening) on the deformation of cylinders, prepared from alloy steels of brands 12KhN3A and 38KhA. An increase in the length of samples during hardening in oil is approximately 4 times less than during hardening in water.

Deformations of bushings (Table 32), prepared from steel 45 and 40Kh, during hardening in oil are significantly less than during hardening in water.

Table 31. Change in the Length of Cylindrical Samples (10 x 100 mm) Depending Upon Hardening Medium (Mochalkin)

Temperature of hardening in °C	Increase in the length of a sample in %		Temperature of hardening in °C	Increase in the length of a sample in %	
	Steel 12KhN3A	Steel 38KhA		Steel 12KhN3A	Steel 38KhA
800	0.03* 0.27**	0.05* 0.22**	900	0.11* 0.44**	0.10* 0.40**
850	0.11* 0.40**	0.07* 0.30**	950	– –	0.13* 0.48**

*Tempering medium — oil.

**Tempering medium — water.

Details of complicated configuration, for the purpose of decreasing hardening strains, are preferably prepared from alloy steels with hardening in oil. Independently of the speed of heating, the temperature of hardening and the speed of cooling during hardening, steel

details possess residual stresses after hardening.

Tempering steel, while lowering these residual stresses, leads to a decrease in the degree of deformation of hardened details.

Table 32. Deformation of Bushings of Steel 45 and 40Kh During Hardening

Dimensions of bushing in mm			Brand of steel	Hardening		Ellipticity in mm	Increase of external diameter in mm
External diameter	Thickness	Length		Temperature in ^{o}C	Cooling medium		
120 48	10 4	150 60	45	830	Water	0.2-0.5 0.2-0.7	0.3-0.7 0.2-0.5
120 48	10 4	150 60	40Kh	830	Oil	0.1-0.3 0.06-0.09	0.1-0.3 0.03-0.08

Residual stresses during tempering decrease through the heating of steel, when with increase of its plasticity the elastic deformations change into plastic; structural transformations during tempering occur with volume changes, decreasing stress.

The magnitude and distribution of residual stresses according to the gage of wall of bushing (D_H = 82 mm, D_{BH} = 50 mm, thickness of the wall being 16 mm), prepared from steel with a content of 0.9% C, are shown in Fig. 16 after hardening in water; moreover, the surface hardness attains HRC 65-66, and hardness of the core attains HRC 40. Maximum compression stresses at the surface of the wall of bushings constitute 30 kg/mm^2 and change into stretching stresses, attaining, in the core of the wall of the bushing, ~70 kg/mm^2 (tangential) and 40 kg/mm^2 (longitudinal). After tempering the bushing at 200^{o}C (surface hardness HRC 61-62 and core hardness HRC 40) the magnitude of the tangential and longitudinal stretching stresses decreases to 50 and 35 kg/mm^2 correspondingly (Fig. 17). The higher the temperature of tempering, the greater the decrease of deformations, obtained during hardening.

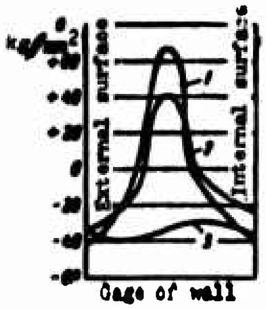


Fig. 16.

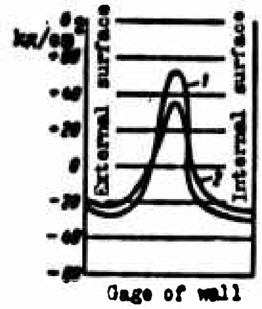


Fig. 17.

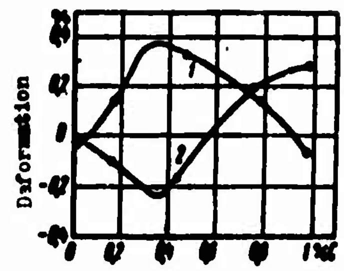


Fig. 18.

Fig. 16. Distribution of residual stresses by gage of the wall of the bushing (steel 0.9% C) after hardening in water: 1) tangential; 2) longitudinal; 3) radial.

Fig. 17. Distribution of residual stresses by gage of the wall of bushing (steel 0.9% C) after hardening in water (Fig. 16) and leave tempering at 200°: 1) tangential; 2) longitudinal.

Fig. 18. The value of deformation of cylindrical samples 100 mm in length and ϕ 25 mm from carbon steel, depending upon the content of carbon after hardening in water: 1) length of sample; 2) diameter of sample.

Nonuniform heating of hardened details during their tempering leads to the formation of thermal stresses.

The speed of cooling of details after tempering (especially during high temperatures of tempering) also affects the appearance of stresses, and the more this speed, the bigger the obtained internal (thermal) stress. Cooling steel after high-temperature tempering in water (with great speed) leads to the formation of residual stresses of high value.

The influence of the composition of steel on the appearing of stress and deformation during hardening is determined chiefly by the content of carbon* (Fig. 18, Table 33). The stresses in steel with a content of carbon of 0.30-0.40% attain the greatest value which is explained by an irregularity of structural transformations in the core and in surface layers of samples (blind hardening).

*Temperature at the beginning of martensite transformation.

Table 33. Magnitude of Residual Stresses after the Hardening in Water of Cylinders with a Diameter of 50 mm of Steel with Different Contents of Carbon

Content of C in steel in %	Maximums of stresses in kg/mm^2		
	Longitudinal	Tangential	Radial
0.025	48	30	30
0.17	40	25	10
0.23	48	20	6
0.30	75	45	13
0.40	70	52	32
0.50	53	28	16
0.60	48	30	16

The magnitude of the grain of steel influences deformations while hardening, whereby significantly large residual stresses appear in coarse-grained and deformation steels than in fine-grained.

The distribution of residual stresses by the gage of hardened and tempered washers, prepared of steel brand 18Kh2N4VA with a different magnitude of grain, shows that in coarse-grained steels (grain No. 2-3), compressing stresses for the external edge of washer attain 10 kg/mm^2, and for the hole the stretching stresses attain 16 kg/mm^2, in fine-grained steels (grain No. 8) these stresses are equal to 4 and 2 kg/mm^2 correspondingly (I. Kontorovich).

The absolute value (and direction) of deformations of steel details during their heat treatment, other things being equal, depends on their dimensions and configuration. Thus, if for details of one form with an increase of size the deformation is increased, then for details of other form, its decrease is possible.

Besides the factors, described for details with homogeneous structure, significant influence is rendered on stresses of cemented detail during heat treatment by the content of carbon in cemented layer and its distribution in the depth of the layer, relation of the depth of cemented layer to the gage of detail, initial content of carbon in the steel, relationship of the dimensions of carburized and noncarburized surfaces of a detail during local cementation, difference in the elastic and plastic state of the cemented layer and core at identical temperatures in the process of heating and cooling, and also the difference of temperatures of martensite transformation of the cemented layer and core. This alone determines the complexity of establishing laws, which would allow beforehand the anticipation of the magnitude and direction of deformation of cemented details.

In practice the nature of deformation is usually established by experimental means.

It is necessary to note that significant part of the total deformation of details, as a result their heat treatment, was apportioned to cementation. For instance, for bushings of steel 20Kh (D_{OTB} = 100; 70, 40 mm; thickness of wall equal to 0.1 D_{OTB}; height equal to 1.5 D_{OTB}) after cementation at 900°C the diameter of the hole significantly decreases, whereby the measure of increase of diameter from 40 to 100 mm the decrease fluctuates from 0.02-0.12 to 0.12-0.35 mm; with subsequent quenching of the bushings (810°C, oil) the decrease in the holes is insignificant. With quenching of the same bushings made of steel 40Kh in oil at 830°C the diameter of the holes is measured by an amount from 0.02-0.08 to 0.10-0.30 mm. For cemented grears, depending upon different factors as a result of cementation, a deformation (decrease or increase of thickness) of

teeth occurs with a related disturbance profile of evolvent and with an increased pulse the norms of the tooth.

Obtaining teeth of gears with a definite prodile of evolvent and maximum pulse of tooth by 0.12-0.18 mm (for gears, manufactured from steel of different brands, for a different purpose) after a full cycle of their heat treatment (without subsequent grinding of the teeth) may be carried out by means of applying special measures.

The deformation of details with simple constructive forms (shafts, axles, small shafts, bushings, flat details), obtained as a result of heat treatment can be defined by magnitude and direction experimentally and considered during preliminary machining by bringing the dimensions to fixed limits by subsequent correction and machining (grinding).

For the purpose of decreasing labor-consumingness of operations of correction and grinding for such details, with success are applied heating during hardening and tempering in special attachments and hardening in tempering machines while rotating in a free or in a pressed condition between rollers (detail of cylindrical form) or in stamps (flat details) are applied with success. Significantly more serious problems are presented by the problem of deformation during the heat treatment of details of complicated configuration and, especially those prepared from cemented and improved steels, subjected to hardening and improved steels, subjected to hardening and tempering for obtaining of high hardness.

Characteristic representatives of this group of details are gear.

For obtaining identical results in deformation, one should narrow the limits of the content of carbon in the steel to 0.05-0.06%; so that, for steel 20Kh the content of carbon is taken from 0.18 to 0.23%; for 12KhN3 — from 0.12 to 0.17%; for 20Kh2N4A — from 0.15 to 0.20%.

Chiefly fine-grained steel (magnitude of grain for average- and high-alloy steels — No. 5-7; for low-alloy steels — No. 4-6) with a capacity for hardening should be applied for gears to ensure obtaining the required mechanical property by the gage of the gear section after heat treatment.

Preliminary heat treatment of blands for gears, besides the elimination of overheating, obtained during stamping, and the preparation of the structure for subsequent heat treatment, should also anticipate obtaining a good workability by cutting.

Gears must be subjected to gas cementation which allows the application of improved attachments, protecting the gears from warping, and also the obtainment of a carburized layer without a coarse singling out of cementite in the form of a grid or grains. Moreover, the process of normalizing the gears after cementation (is excluded superfluous heating and its related formation of cinder) and purification, leading to the distortion of the profile are excluded.

During gas (or liquid) cementation of steel of certain brands (18KhGT, 20KhM, 20NM) the possibility appears of hardening directly after cementation (without repeated heating). It is necessary to harden a gear of large diameter and small thickness in special presses in a pressed state which significantly decreases their warping.

In order not to obtain cinders, gears should be heated in furnaces in a controlled atmosphere or in a salt baths. Isothermal and step hardening decrease deformations. Thus, during the usual hardening in oil ($t \approx 40^{\circ}C$) of a cemented shaft-gear (steel 20NM) the pulse of one end of a shaft amounts to 0.43 mm, the pulse on the initial circumference of gear amounts to 0.56 mm and the pulse of the other end amounts to 0.64 mm; during step hardening in oil at a

temperature 200°C the shown magnitudes of deformations are lowered to 0.15; 0.20 and 0.25 mm correspondingly while preserving the hardness of core and surface layer of the detail in the required limits.

Isothermal hardening of gears, prepared from steel 18Kh2N4VA, is conducted under conditions (after cementation) of heating to 780-790°C, holding at this temperature, cooling in a furnace or bath at a temperature of 150-170°C and holding for 3 hours. Further, in air, gives a sharp decrease of deformations (pulse of initial circumference), practically preserving the magnitude of the pulse in the initial state (i.e., after cementation). Besides, the mechanical properties and hardness of the core and surface layer correspond to the requirements of technical conditions (σ_B = 124-130 kg/mm^2; δ = 12-13%; ψ = 60-62%, a_H = 14-14.5 kg-m/cm^2; HRC 40-41 core and HRC 58-60 surface).

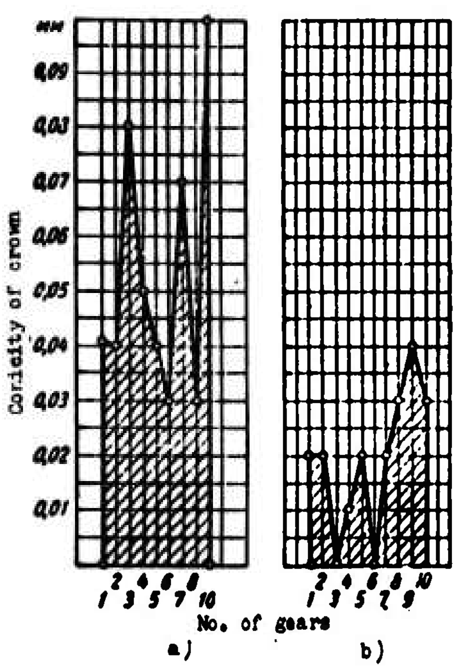


Fig. 19. Influence of step hardening of gears of steel 20Kh2N4A on conicity of crown: a) usual hardening; b) step hardening.

For gears of steel 20Kh2N4A with an external diameter of 180 mm and length of tooth of 40 mm (gear with nave) after cementation and hardening at a temperature of 800°C in oil at a temperature of 60°C (usual hardening) the conicity and ellipseness of crown reaches 0.1 mm and more; during step hardening of gears at 800°C in hot (180°C) oil while holding in it for 5 min the conicity and ellipseness of crown do not exceed 0.04 mm (Fig. 19 and 20), i.e., their magnitude is 2.5 times less. Furthermore, the mechanical properties and hardness of core and surface layer are in accordance with the requirements of technical conditions.

For gears having an external diameter of 155 mm, diameter of hole of 65 mm and length of tooth of 35 mm from steel brand 20KhNM after cementation and hardening at a temperature of 845°C in oil having a temperature of 50°C, the conicity exceeds the bounds of permissible magnitude (0.075 mm max) and amounts to 0.101-0.178 mm; during step hardening of these gears at a temperature 845°C in oil having a temperature of 180°C (holding for 6 min and further cooling in air) conicity is within the limits of 0.025-0.075 mm.

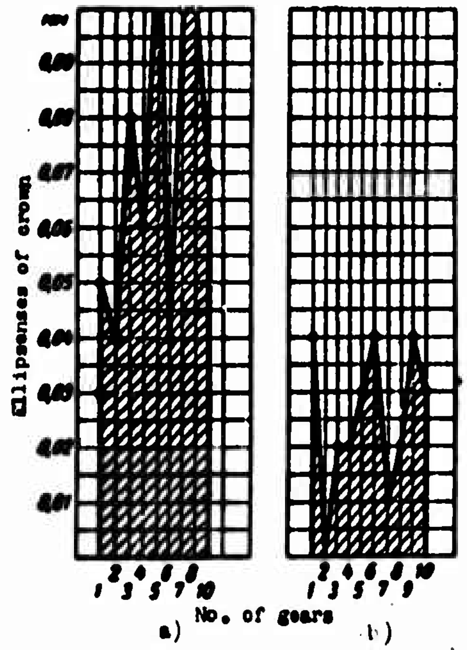


Fig. 20. Influence of step hardening of gears of steel 20Kh2N4A on ellipseness of crown: a) usual hardening: b) step hardening.

The application of the indicated measures and strict observance of methods and conditions of heat treatment allow the establishment of regularity of deformation of gears and the bringing of its magnitude to a minimum. In this case there is the possibility, when machining of considering the distortion of the profile of the tooth beforehand and changing the dimensions of gear and excluding difficulty in the operation of grinding teeth.

THERMAL TREATMENT OF NONFERROUS METALS AND ALLOYS*

Aluminum and Its Alloys

Technical aluminum. Semi-finished products of technical aluminum of brands AD and AD1 in the form of sheets, rods, pipes, wire and

*For the mechanical properties of nonferrous metals and alloys obtained by various means and with various regimes of heat treatment, see Vol. 6.

rivets after cold treatment are subjected to recrystallizational annealing in the interval of temperatures of 350-410°C. Furthermore there occurs a replacement of deformed crystals by new equiaxial crystals, and also a removal of riveting and internal stresses (Fig. 21-23).

Deformed alloys. Alloys AMts, AMg, AMg3, AMg5V, AMg5P and AMg6T, not strengthened by heat treatment, are applied in three states: annealed (designated by letter M), semi-cold hardened (П) and cold hardened (H). Depending upon this their mechanical properties can be different.

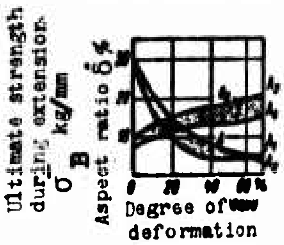


Fig. 21.

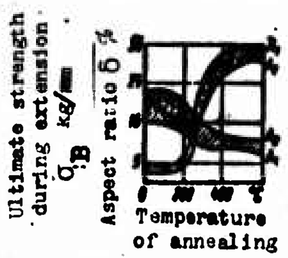


Fig. 22.

Fig. 21. Dependence of mechanical properties of aluminum of brands A_1 and A_2 on the degree of deformation.

Fig. 22. Dependence of mechanical properties of aluminum of brands A_1 and A_2 on the temperature of annealing.

Recrystallizational annealing cold hardened half-finished products (sheets, profiles, rods, wire and rivets) is recommended to be produced at a temperature of 350-410°C, depending upon the brand of alloy, with cooling in air or in water. A diagram of recrystallization of aluminum-magnesium alloy of type AMg is shown in Fig. 24.

The microstructure of the alloy AMts consists of a mixture of crystals of a solid solution of Al(Mn) and crystals of the chemical compound Al_6Mn. The small crystals of Al_6Mn, being disposed between crystals of Al(Mn), prevent the growth of the latter during heightened temperatures of annealing. The microstructure of alloys AMg, AMg3, AMg5 and AMg6T is polyhedral, consisting of crystals of solid solution of magnesium in aluminum. Therefore, these alloys, during heightened temperatures of annealing, are inclined to the formation of a large grain.

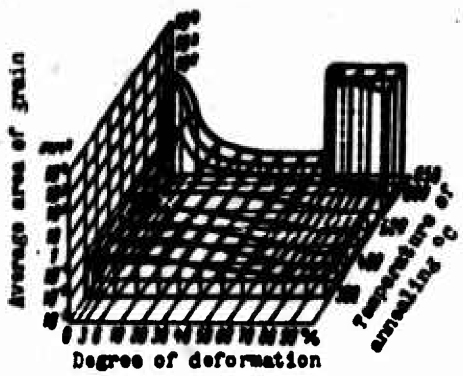


Fig. 23. Diagram of recrystallization of aluminum with a cleanness of 99.6%.

<u>Alloys, strengthened by heat treatment.</u> For sheets, sections and pipes alloys of four basic brands are applied: D1, D6, D16 and V95. Alloys D1, D6 and D16 belong to the system Al-Cu-Mg, alloy V95 belongs to the system Al-Zi-Mg-Cu. Recommended regimes of their heat treatment are given in Table 34.

Heat treatment of aluminum alloys is designated by the letters: M – annealing, T – hardening and natural aging; T1 – hardening and artificial aging. In Fig. 25 a diagram of recrystallization aluminum alloy D1 is given. The optimum temperature of hardening alloy D1 is determined by curves, showing the dependence of mechanical properties on the temperature of hardening (Fig. 26). The most profitable temperature of hardening alloy D1 is equal to 500°C: at a temperature 520°C it already experiences overheating, but at a temperature 530°C it experiences overburning. The aging process for this alloy is shown in Fig. 27. The process of aging this alloy D1 amounts to 2 hours, and the time of full hardening amounts to 5 days. The chemical compound $CuAl_2$ is a strengthened alloy of D1.

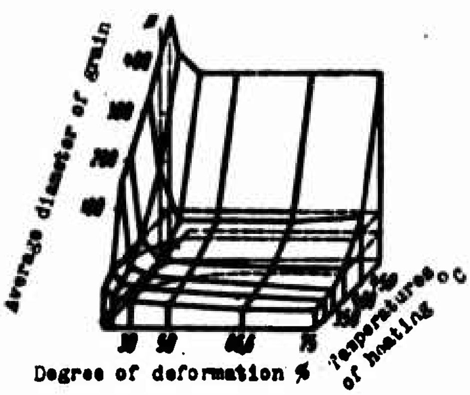


Fig. 24. Diagram of recrystallization alumino-magnesium alloy of type AMg consisting of: 3% Mg, and the rest, aluminum.

Alloy D16 differs from alloy D1 by its higher content of magnesium and smaller permissible content of iron and silicon. Its relation to heat treatment is analogous to alloy D1, but its basic

strengthener during aging is phase S, i.e., the chemical compound Al_2CuMg. The optimum temperature of hardening of alloy V95 lies in the interval 465-475°C. The diffusion of magnesium and zinc in plating a layer starts at a higher temperature. Overheating is observed at a temperature of 510°C, bubbles appear at a temperature of 515°C on the surface of an alloy; fusion takes place at a temperature of 540°C.

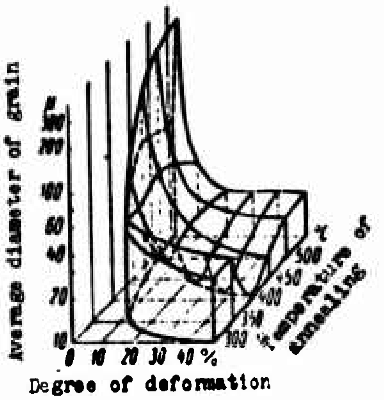


Fig. 25. Diagram of recrystallization of duralumin of brand D1 composed of 4% Cu, 5% Mn, 0.5% Mg, and the rest aluminum; treatment: cold settling and annealing for 15 hours.

Alloy V95 is more sensitive to the interruption between removal from a furnace and cooling in water during hardening than duralumin of brands D1 and D16. Therefore half-finished products from alloy V95 must be transferred from the furnace to water as fast as possible, in not more than 5 sec.

The process of natural aging of alloy V95 at room temperature continues for 60 days; at 0°C it is held for 1 day; and for 7 days, at 18°.

The mechanical properties of naturally aged alloy are the same, as alloy which has undergone artificial aging, but its resistance to corrosion is significantly lower.

The mechanical properties of alloy V95 which is artificially aged at various temperatures are shown in Table 35.

Basic strengtheners of alloy V95 during artificial aging are the chemical compounds: $MgZn_2$ and $Al_2Mg_3Zn_3$ (i.e., phase the T system Al-Zn-Mg).

Homogenization of ingots of alloy V95, which is conducted for the purpose of levelling the chemical heterogeneity and decreasing liquation, is carried out at a temperature 460-480°C.

For manufacture of rivets, alloys D18 and V65 are applied, which is recommended to be thermally processed by the conditions, shown in Table 36. After heat treatment, alloy D18 has $\tau_{cp} \geq 19$ kg/mm^2, and alloy V65 has $\tau_{cp} \geq 25$ kg/mm^2.

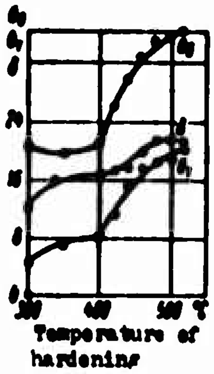


Fig. 26. Dependence of mechanical properties of duraluminum on the temperature of hardening.

Heating of hardened and aged alloys D18 and V65 for 5-60 min at a temperature of 100°C causes the indicated results which disappears only after 10 days. Alloy D18 and V65 may be unrivetted at any time after aging.

Besides these alloys, the highly durable alloy of brand V94 is applied for the manufacture of rivets of which are unriveted in a hardened and artificially aged state. Wire, prepared from this alloy, in a thermally treated state has a shear strength of not less than 29 kg/mm^2.

Aluminum alloys of three brands: D1, AK6 and AK8 are used for stamps.

The heat treatment of alloy D1 was considered above. Alloy AK6 is subjected to hardening and artificial aging, as a result of which it has sufficiently high mechanical properties. The main strengtheners of this alloy during aging is the chemical compound Mg_2Si; the second strengthener may be considered to be phase W, i.e., chemical compound $Al_2CuMgSi$.

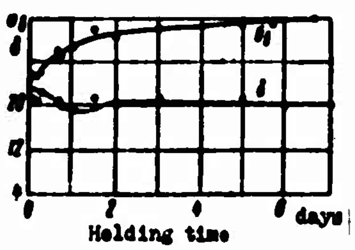


Fig. 27. Change in mechanical properties of duralumin during aging at room temperature.

Alloy AK8 possesses very high mechanical properties. Its main strengthener during artificial aging is the chemical compound Mg_2Si, its second strengthener is the chemical compound $Al_2CuMgSi$.

Conditions of heat treatment and mechanical properties of these alloys after heat treatments are shown in Table 37.

Table 34. Conditions of the Heat Treatment of Aluminum Alloys for Sheets, Profiles and Pipes

Brand of alloy	Annealing		Hardening		Aging	
	Temperature in °C	Cooling	Temperature in °C	Cooling	Temperature in °C	Holding
D1	340-370	In air	490-505	In water ≤ 40°C	Room	4 days
D6	340-370	In air	498-503		Room	
D16	340-370	In air	490-500		Room	
V95	420-440	With a furnace	465-475		In plated state 120-125	24 hours
					In unplated 140	12 hours

Table 35. Mechanical Properties of Alloys V95 after Artificial Aging

Temperature of aging in °C	Time of holding in hours	Mechanical properties		
		σ_B	σ_T	δ in %
		in kg/mm²		
100	54	54.0	45	11
120	16-24	52.5	47	10
130	12-16	52.5	47	10
140	8-12	51.0	46.5	9
160	4-5	50.0	45	9

Table 36. Conditions of Heat Treatment of Aluminum Alloys for Rivets

Brand of alloy	Hardening		Aging	
	Temperature in °C	Cooling	Temperature in °C	Holding
D18	495-505	In water	Room	4 days
V65	510-520		75	24 hours

Table 37. Conditions of Heat Treatment and Mechanical Properties of Aluminum Alloys for Stamps

Brand of alloy	Hardening		Aging		Mechanical properties			
	Temperature in $^{\circ}C$	Cooling	Temperature in $^{\circ}C$	Holding	σ_B in kg/mm^2	σ_T in kg/mm^2	δ in %	HB in kg/mm^2
D1	490-505	In water	Room	4 days	38	23	12	95
AK6	505-515	In water	150-160	12-15 hr	38	28	10	100
AK8	500-510	In water	180 ± 5	5-8 hr	46	35	10	130

Foundry alloys of aluminum. By chemical composition, foundry aluminum alloys may be divided into five groups:

1) high-siliceous Silumin (AL2, AL4, AL9 and MVTU-1);

2) low-siliceous Silumin (AL3, AL5 and AL6);

3) zinc Silumin (AL11);

4) copper-aluminum alloys (AL7, AL12 and AL19);

5) magnesium-aluminum alloys (AL8 and AL13).

High-siliceous aluminums. Alloy AL2 is used in machine building and instrument-making without heat treatment. Alloy AL4 is subjected to hardening and artificial aging (Table 38). Mechanical properties for samples of alloy AL4 which has been separately poured in earth, modified hardened and has undergone aging must not be less than: $\sigma_B = 23$ kg/mm^2; $\delta = 3\%$; HB 65 kg/mm^2 and during casting in a metallic form not less than: $\sigma_B = 23$ kg/mm^2; $\delta = 3\%$; HB 70 kg/mm^2.

In process of hardening alloy, i.e., at a temperature of 535°C magnesium, manganese (with the exception of that part, which is connected with iron) and part of silicon change into a solid solution. In process of aging from the solid solution at first separates into submicroscopic crystals of silicon, then into crystals of chemical

compound Mg_2Si. Besides mechanical properties in the function of aging time are changed by flux (Fig. 28 and 29). However if alloy is subjected to isothermal treatment (i.e., hardening in melted saltpeter, heated to 180°C, and aged in this bath), then two maxims are revealed on the curves of change of mechanical properties of which one corresponds to the singling out of crystals of silicon, while the other corresponds to singling out of crystals of chemical compound Mg_2Si.

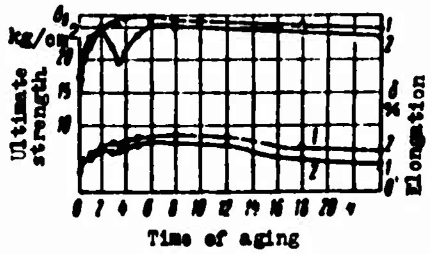


Fig. 28. Change of ultimate strength and lengthening of alloy AL4 depending upon the time of aging: 1) usual heat treatment; 2) isothermal treatment.

As a result of isothermal treatment alloy AL4 obtains mechanical properties, which lie in the norms of technical conditions, but with some lowering of durability and some increase of length which may be seen on Fig. 28. Furthermore, warping of details is a few times smaller than in the case of hardening in water.

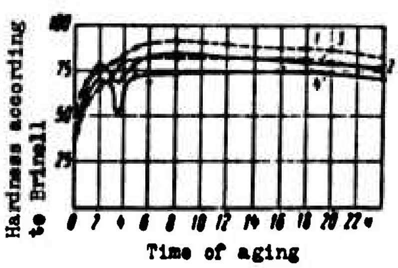


Fig. 29. Change of hardness and microhardness of alloy AL4 depending upon the time of aging: 1) hardness after usual heat treatment; 2) hardness after isothermal treatment; 3) microhardness after usual heat treatment; 4) microhardness after isothermal treatment.

It is necessary to remember that isothermal treatment may be applied only to thin-walled details, which can ensure sufficiently rapid cooling during hardening in a hot medium. Thick-walled details in this case obtained reduced mechanical properties.

Alloy AL9 has lower mechanical properties than alloy AL4. Conditions of the heat treatment of alloy AL9 are given in Table 38. Alloy MVTU-1 belongs to the system Al-Si-Mg-Cu with the additions Mn and Ti.

Table 38. Conditions of Heat Treatment of High-Siliceous Silumin

Brand of alloy	Hardening			Aging		
	Temperature in °C	Holding	Cooling in water at a temperature	Temperature in °C	Holding in hour	Cooling
AL4	535^{+5}_{-10}	2-6	$\leq 80^\circ$	180 ± 5	6-7	In air
AL9	535 ± 5	12	50-100°	150 ± 10	1-3	In air

Low-siliceous Silumin. Conditions of heat treatment and typical mechanical properties of low-siliceous Silumin are given in Table 39.

Zinc Silumin. To this group belongs only one alloy of brand AL11, which, ensures high mechanical properties without heat treatment: casting in earth σ_B = 20 kg/mm^2, δ = 2%; HB 80 kg/mm^2; casting in metallic forms: σ_B = 25 kg/mm^2; δ = 1.5%; HB 90 kg/mm^2.

Copper-aluminum alloys. Alloys, belonging to this group, may be divided into two groups: alloys with a content of copper of not more than 5.65%, which can be homogenized and hardened into a solid solution, and alloys with a content of copper of more than 5.65%, which contain eutectic and are less sensitive to heat treatment.

Alloys AL7 and AL19 belong to the first group, alloy AL12 belongs to the second.

Alloy AL7, after hardening, slowly ages and after several months approaches the properties of a hardened and artificially aged state. Conditions of heat treatment of alloy AL7 are shown in Table 40.

Alloy AL19 has higher mechanical properties at room temperature than alloy AL7, and higher heat resistance. Conditions of heat treatment of alloy AL19 are shown in Table 40. Alloy AL12 is used rarely. It is not subjected to heat treatment.

Table 39. Conditions of Heat Treatment and Typical Mechanical Properties of Low-Siliceous Silumin

Brand of alloy	Hardening			Aging		Mechanical properties				
	Temperature in °C	Holding in hours	Cooling	Temperature in °C	Holding in hours	σ_B in kg/mm²	σ_T in kg/mm²	δ in %	σ_{-1} in kg/mm²	HB in kg/mm²
AL3	Not subjected to heat treatment					17	11	2	6	70
AL5	525^{+5}_{-10}	4	In water	180 ± 5	5	24	17	3	6	80
	525^{+5}_{-10}	4	50-100°	230 ± 5	5	20	16	1.5	5	60
AL6	Not subjected to heat treatment					17	11	3	5	50

Table 40. Conditions of the Heat Treatment of Copper-Aluminum Alloys

Brand of alloy	Hardening			Aging		
	Temperature in °C	Holding in hours	Cooling	Temperature in °C	Holding in hours	Cooling
AL7	515 ± 5	10-15	In water to 50-100°	150 ± 5	2-4	In air
AL19	530	8	—	—	—	—
	540	8	In water to 90°	175	3	In air

Table 41. Conditions of Heat Treatment of Heat-Resisting Aluminum Alloys

Brand of alloy	Hardening			Aging		
	Temperature in ^{o}C	Holding in hours	Cooling	Temperature in ^{o}C	Holding in hours	Cooling
AL1	510-520	2-4	In water to $100^{o}C$ or in air	210-230	2-4	On air
AK2, AK4	510-520	—	In water	165-175	15-18	The same
AK4-1	525-540	—	The same	180-190	10	The same
VD-17	505-510	2	The same	170	16	The same

Magnesium-aluminum alloys. Alloys of aluminum with magnesium, containing from 3 to 12% magnesium, can be subjected to homogenization and hardening. After heat treatment they have a polyhedral structure, consisting of crystals of solid solution of magnesium in aluminum, and differ by their high mechanical properties. During the thermal treatment of a detail of these alloys it is necessary to smear them with fire clay, in order that they do not oxidize at high temperatures.

Heat treatment of alloy AL8 consists in hardening in the following conditions: heating to 435 ± 5^{o}, holding for 15-20 hours and cooling in water at a temperature 20 or $60\text{-}80^{o}$.

Alloy AL13 is used in industry without heat treatment, since its quantity of magnesium cannot ensure a sufficient effect of aging.

Heat-resistant alloys of aluminum. Such aluminum alloys, which preserve sufficiently high mechanical properties to a temperature of 300^{o} are called heat-resisting. These alloys can be poured (brand AL1) or deformed (brand AK2, AK4, AK4-1, VD17).

In aluminum alloys of brands AL1, AK4, AK4-1 and VD17 phases, which stand out during aging, are chemical compounds Al_2Cu, Al_2CuMg, $Al_2CuMgSi$ and phase $Cu_xNi_yAl_z$. These phases possess a small speed of coagulation and cause heat resistance of the mentioned alloys.

Regarding role of separate elements, entering into the considered alloys, the basic influence on heat resistance is rendered by copper and magnesium; a smaller role is played by silicon and still a smaller role is played by iron and nickel. The latter elements are considered harmful in heat-resisting alloys, if they are present in quantities, exceeding those necessary for the formation the chemical compound $FeNiAl_9$. Conditions of heat treatment of heat resistant aluminum alloys are shown in Table 41.

Copper and Its Alloys

Technical Copper. In its annealed state copper has high plastic properties, but relatively low durability. Cold deformation significantly increases the durability of copper, but sharply lowers its plasticity. For removing riveting and decreasing its hardness copper is subjected to recrystallizational annealing; the temperature for beginning recrystallization of copper is near 200°C. For a full restoration of the plasticity of half-finished products, it is recommended annealing to be done at a temperature of 500-550°C in a slightly oxidizing atmosphere, in order to avoid so-called "hydrogen illness," to which copper can be subjected during heating in a restoring atmosphere. Cooling after annealing may be conducted at any speed: in a furnace and in air.

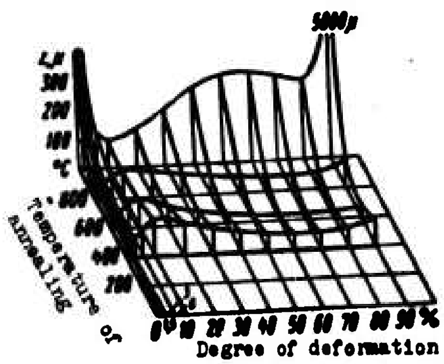


Fig. 30. Diagram of recrystallization of copper.

In Fig. 30 a diagram of the recrystallization of copper is shown, but on Fig. 31, curves of the change of properties of copper are shown depending upon the temperature of annealing (tape of roofing paper, 2.5 mm, subjected to annealing of cold deformation by 70%).

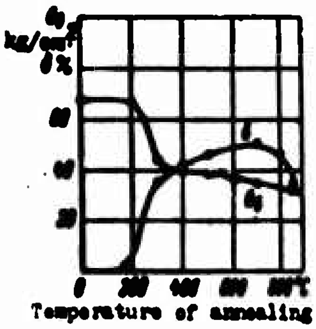


Fig. 31. Change of properties of riveted copper after annealing at different temperatures.

Brasses. Copper-zinc brasses of brands L96, L90, L85, L80, L70, L68 constitute single-phase alloys with structure of α-solid solution. α-brasses do not experience phase transitions to a solid state, therefore they cannot be subjected to hardening and normal annealing.

Table 42. Conditions of Annealing and Mechanical Properties of Copper-Zinc Brasses, Processed by Pressure

Brand of alloy	Temperature of annealing in °C	Temperature of annealing for removal of internal stresses in °C	Mechanical properties		
			σ_B in kg/mm²	δ in %	HB in kg/mm²
L96	540-600	–	24	50	–
L90	650-720	200	26	45	53
L85	650-720	160-200	28	45	54
L80	600-700	260	32	52	53
L70	520-650	260-270	32	55	–
L68	520-650	260-270	32	55	–
L62	600-700	270-300	33	49	56

In process of cold deformation (rolling, drawing) brasses obtain rivets. For removal of riveting, recrystallizational annealing at a temperature of 600-700°C with cooling in air is produced. After annealing the plasticity of brass sharply increases.

Brasses, containing more than 20% Zn, which are insignificantly deformed, crack during storage in humid atmosphere. In order

to avoid the formation of cracks in brass articles, subjected to prolonged storage, they are subjected to low-temperature (200-300°C) annealing for several hours.

The conditions of annealing and mechanical properties of copper-zinc brasses are given in Table 42.

The change of mechanical properties of certain copper-zinc brasses, depending upon the temperature of annealing, is shown on Fig. 32-34. Diagrams of the recrystallization of brasses L68 and L62 are shown in Fig. 35 and 36.

Besides simple brasses, i.e., alloys of copper with zinc, special brasses have wide application in technology, the composition of which includes lead, tin, silicon, aluminum, manganese, nickel, iron.

The conditions of annealing and the resultant mechanical properties of special brasses, processed by pressure, are given in Table 43. The change of mechanical properties of special brasses, depending upon the temperature of annealing, is represented in Fig. 37-40.

Castings from brasses, which must have small deformations in process of exploitation, are annealed at a temperature of 600-650°C for 2-4 hours.

Bronzes. Bronzes are divided into cast and deformed.

Deformed bronzes, depending upon their chemical composition, are divided into stannous and nonstannous.

Cast bronzes, as a rule, are not subjected to heat treatment.

Stannous bronzes. The durability of deformed bronzes (single-phase, obtained either during a low concentration of tin, or after special diffusion annealing) increases with an increase of the degree of deformation, and plasticity drops. For increase of plasticity, bronzes of brands Br. OF6.5-0.4, Br. OF4-0.25, Br. OTsS4-3,

Br. OTsS4-4-2.5, Br. OTsS4-4-4 are subjected to recrystallizational annealing at a temperature of 600-650° (cooling in a furnace or in air), as a result of which the properties of bronzes are changed (Fig. 41).

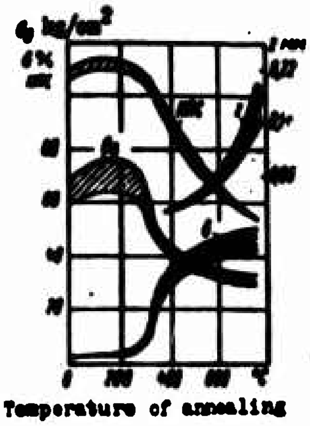


Fig. 32.

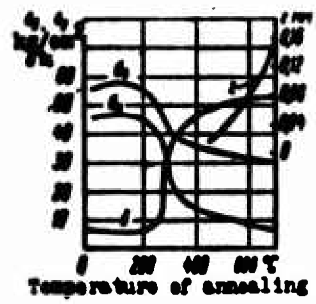


Fig. 33.

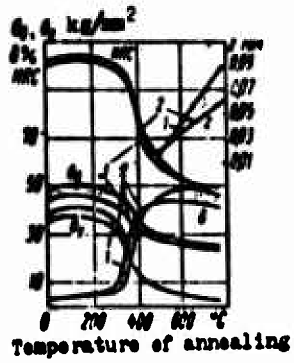


Fig. 34.

Fig. 32. Change of mechanical properties of brass L68, depending upon the temperature of annealing. Duration of annealing of one hour. Initial magnitude of grain: 0.015 and 0.07 mm.

Fig. 33. Change of mechanical properties of brass L80 depending upon the temperature of annealing. Duration of annealing of one hour.

Fig. 34. Change of mechanical properties of brass L90, depending upon the temperature of annealing. Duration of annealing of one hour. Initial magnitude of grain: 1) 0.015; 2) 0.07 mm.

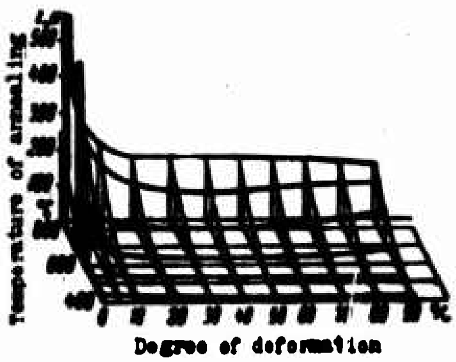


Fig. 35. Diagram of recrystallization of brass.

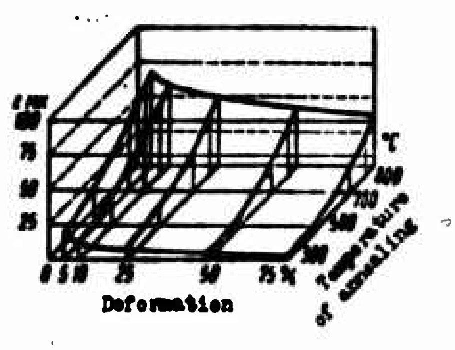


Fig. 36. Diagram of recrystallization of brass L62.

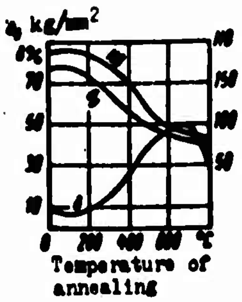


Fig. 37.

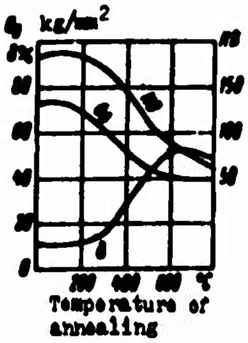


Fig. 38.

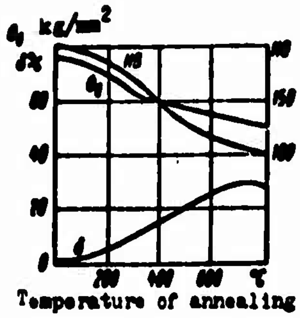


Fig. 39.

Fig. 37. Change of mechanical properties of brass LAZh60-1-1, depending upon the temperature of annealing. Duration of annealing of 1 hour.

Fig. 38. Change of mechanical properties of brass LZhMTs59-1-1, depending upon the temperature of annealing. Duration of 1 hour.

Fig. 39. Change of mechanical properties of brass LMtsA57-3-1, depending upon the temperature of annealing. Duration of annealing of 1 hour.

Table 43. Conditions of Annealing and Mechanical Properties of Special Brasses, Processed by Pressure

Brand of alloy	Temperature of annealing in °C	Temperature of annealing for removal of internal stresses in °C	Mechanical properties		
			σ_B in kg/mm²	δ in %	HB in kg/mm²
LA85-0.5	650-700	–	30	60	54
LA77-2	600-650	300-350	40	55	60
LAN59-3-2	600-650	350-400	38	50	75
LN65-5	600-650	300-400	40	65	–
LZhMts59-1-1	600-650	–	45	50	88
LMts58-2	600-650	–	40	40	85
LO90-1	650-720	–	28	45	58
LO70-1	560-580	300-350	35	60	–
LO62-1	550-650	350-370	40	40	–
LO60-1	550-650	–	38	40	–
LS74-3	600-650	–	35	50	–
LS64-2	620-670	–	35	55	–
LS63-3	620-650	–	35	55	–
LS60-1	600-650	–	37	45	–
LS59-1	600-650	285	40	45	90
LK80-3	–	–	30	58	60*

*Hardness according to Vikkers.

Table 44. Conditions of Annealing of Aluminum Bronze

Brand of alloy	Br. A5	Br. A7	Br. AZh 9-4	Br. AZts 10-4-4	Br. AMts 9-2	Br. AMts 10-2
Temperature of annealing in $^{\circ}C$	600-700	650-750	700-750	700-750	650-750	650-750

Aluminum bronzes of brands Br. A, Br. AZh, Br. AZhN, Br. AZhM are subjected to recrystallizational annealing for the removal of riveting at a temperature 600-750°C, depending upon the brand of alloy (Table 44).

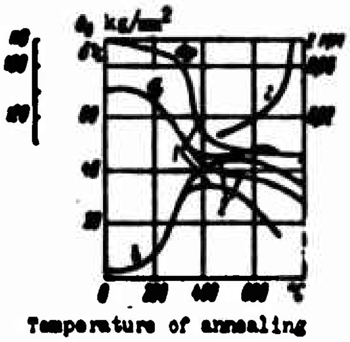


Fig. 40.

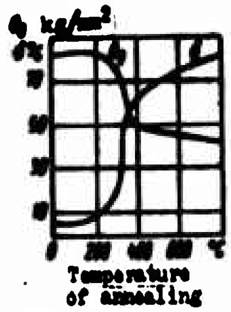


Fig. 41.

Fig. 40. Change of mechanical properties of brass LC59-1, depending upon the temperature of annealing. Duration of annealing of 1 hour: 1) hardening; 2) slow cooling.

Fig. 41. Dependence of mechanical properties of bronze Br. OF 6.5-0.4 on the temperature of annealing.

Certain special bronzes can be strengthened by means of hardening and subsequent tempering. Thus, for bronze Br. AZhN10-4-4, after hardening at 920°C with cooling in water and tempering at 650°C with cooling in air, $\sigma_B = 65$ kg/mm², $\delta = 5\%$, HB 200-240. For bronze Br. AZhMts10-3-1.5 after hardening at 850°C in water and subsequent tempering at 350-450°C $\sigma_B = 80$ kg/mm², $\delta = 9\%$, HB 218.

In siliceous bronzes, containing nickel, a combination of high durability ($\sigma_B = 50$ kg/mm²) and high plasticity ($\delta = 15\%$) can be obtained, if one were to produce hardening at 875°C and tempering at 450°C.

Significantly interesting is beryllium bronze Br. B2, which, after hardening, at 780 + 10°C in water, is soft and is plastic (σ_B = 50 kg/mm², δ = 30%, HB 100). After hardening at 780°C and tempering at 320°C for 2 hours or at 350°C for 1 hour 30 min it becomes durable and hard (σ_B = 130 kg/mm² and HB 370), i.e., hardening with tempering increases durability almost by 3 times, but hardness by 4 times. The temperature of tempering for bronze Br. B2.5 is 285°C for 3 hours or 320°C for 1 hour).

Titanium and Its Alloys

Titanium and its alloys for attaching the necessary properties to them are subjected to different forms of thermal treatment:

1) recrystallizational annealing for the removal of the effect of cold deformation;

2) vacuum annealing for the removal of hydrogen;

3) strengthening heat treatment;

4) softening heat treatment.

Annealing of cold-deformed titanium and its alloys. Annealing of titanium and its alloys, after cold deformation, is produced at the usual furnace atmosphere with holding for 15 min to 1 hour, depending upon the thickness of articles. Temperatures of annealing have to be coordinated with temperatures of recrystallization of titanium alloys, which in most cases are within limits 500-700°C. Actually, annealing is carried out at the following temperatures (in °C):

Sheets of technical titanium of brands VT-1 and VT1-2	500-550
Rods and forgings of technical titanium of brands VT1-1 and VT1-2	650-700
Rods, forgings and stampings of alloys of titanium of different brands	650-700

Annealing of half-finished products, having small thickness, is recommended to be produced in a vacuum or in an atmosphere of chemically pure argon, since, for thin-walled articles, diffusion of oxygen may be caused through isolating the material.

Vacuum annealing. Annealing of half-finished products and details from titanium alloys in a vacuum has the purpose of lowering the content of hydrogen and increasing their plasticity and is produced at a temperature of 700-800°C with holding for 1-2 hours, depending upon the thickness of wall of the details. Cooling together in a furnace of temperature 200°C. Then furnace is filled with dry air its pressure is even with the atmospheric. During annealing the vacuum is supported at a level 10^{-3} - 10^{-4} mm rm.cm.

Strengthening heat treatment. If one were to take an alloy with ($\alpha + \beta$)-structure, which contains a sufficient quantity of one or several β-stabilized elements, then during its heating to a high temperature, lying in region of ($\alpha + \beta$), part of the crystals α will change into crystals β', whereby, the higher the temperature of heating, the greater the quantity of crystals α will be used.

During fast cooling, crystals β' will remain without change and will exist at a room temperature in a metastable state. These transformations may be recorded thus $\alpha + \beta \rightarrow \alpha + \beta' + \beta$.

Subsequent aging of such alloys at temperatures, lying within the limits of 430-540°C, will cause gradual transformation of β'-crystals into α-crystals, where the latter ones will be in a finely-dispersed state. As a result of this process, hardness and durability of alloy will be increased, and plasticity will drop.

Selecting the temperature of hardening and the temperature and duration of aging, may, for every alloy, obtain various mechanical properties. Thus, for instance, changing the temperature of hardening

from 620-955°C and the temperature of aging from 485 to 540°C, it is possible for alloy VT6 to obtain a limit durability from 98 to 125 kg/mm^2 and yield point from 70 to 115 kg/mm^2.

During heat treatment of heat-resisting alloys the duration of aging should be sufficient for complete decomposition of ω-phase, although, besides durability, the characteristics and will be somewhat lowered.

Thus, the heat treatment of titanium alloys, having the purpose of increasing durability, should be executed in two stages:

1) heating and holding of alloys at a temperature, corresponding to $(\alpha + \beta)$-region with subsequent cooling in water;

2) aging at a temperature 430-540°C until obtaining the maximum durability or until full decomposition of ω-phase.

It is obvious that such heat treatment may be useful only for alloys, having a $(\alpha + \beta)$-structure and containing in its own composition a sufficient quantity of β-stabilizing elements. Single-phase alloys with a α- or β-structure cannot be formed during the heating of a stable β'-phase and, consequently, cannot change its own properties and during aging.

The effect of aging $(\alpha + \beta)$-alloys depends on the quantity of their available β'-phase, which, in turn, depends on the temperature of hardening.

As an example of strengthening heat treatment it is possible to report that alloy VT6, after hardening at a temperature of 845°C, with cooling in water and aging at a temperature of 450-650°C, has a coefficient of durability of 120 kg/mm^2, since until such treatment the alloy had σ_B = 95 kg/mm^2.

Conditions of strengthening heat treatment have to be fixed for every alloy, proceeding from the requirements of durability and

plasticity.

Heat treatment for the increase of plasticity of titanium alloys. If the transfer of an alloy into a state of maximum plasticity is required (for treatment by pressure at room temperature), then the best form of heat treatment will be hardening with cooling in water without subsequent aging.

Furthermore, the temperature of hardening should lie, for upper limit, within the $(\alpha + \beta)$-region.

Practice shows that alloy VT6, after hardening at 845°C, with cooling in water, has the lowest yield point and the biggest plasticity.

Nickel and Its Alloys

Technical Nickel. Half-finished products of nickel are subjected to recrystallizational annealing. Depending upon requirements the annealing is produced both in an oxidizing atmosphere, an in an atmosphere without oxidation. The temperature of annealing is within the limits of 700-800°C. In its annealed form technical nickel has $\sigma_B = 65$ kg/mm^2, $\delta = 33\%$, HB 60. Annealing nickel in an atmosphere without, oxygen is produced in an atmosphere saturated with hydrogen, generating gas, dissociated ammonia and others. The presence in a furnace of an atmosphere of sulfur and its combinations is impermissible inasmuch as the saturation of sulfur causes a hot brittleness of nickel.

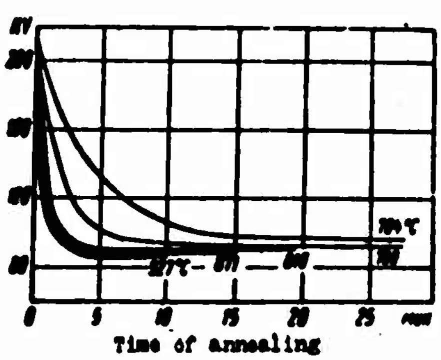


Fig. 42. Hardness of nickel depending upon time and temperature annealing.

In the absence of gas a protective atmosphere without oxygen annealing of details is produced in metallic boxes with the addition of a small quantity of charcoal. After the termination of annealing the boxes are not open to cooling. While annealing of wire in

bales, to keep the coils from sticking, it is dipped in a solution of calk in water and dried before it is packed.

A change of hardness, depending upon temperature and time of annealing, is represented on Fig. 42, and a diagram of recrystallization is shown in Fig. 43.

Alloys of nickel. Among the constructional alloys of nickel the best known is the alloy Monel-metal of brand NMZhMts 28-2.5-1.5, possessing high a corrosional stability in acids and caustics. Basic impurities of this alloy — Cu, Fe, Mn and Co — form, with nickel, a solid solution and increase its electrical resistance, hardness and durability. Manganese, moreover, increases heat resistance of nickel.

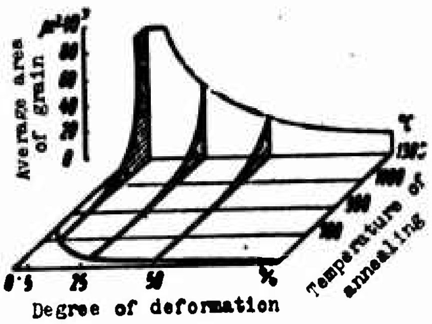


Fig. 43. Diagram of recrystallization of nickel.

Monel-metal in the form of sheets, bands and rods is subjected recrystallizational annealing at a temperature of 800-850°C and in the annealed state has σ_B = 49-60 kg/mm^2, δ = 30-50% and HB 110-140.

Annealing of nickel alloys, without oxidation, is produced by the same method as technical nickel.

A change of mechanical properties of Monel, depending upon temperature, is shown in Fig. 44. A change of hardness of Monel-metal, depending upon time and temperature of annealing, is given in Fig. 45, a diagram of its recrystallization is shown in Fig. 46.

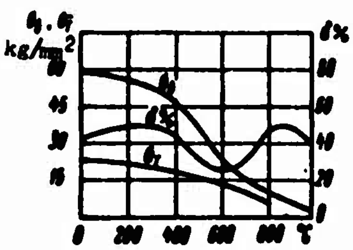


Fig. 44. Change of mechanical properties of Monel depending upon temperature.

Mechanical properties of Monel-metal may be increased by means of introducing alloy elements: aluminum, silicon, cobalt

and other metals. Thus, Monel-metal of brand K, containing 2-4% Al, 1% Mn, 1% Si, < 2% Fe, can be subjected to hardening and strengthening tempering. Furthermore, aluminum will form a chemical compound with

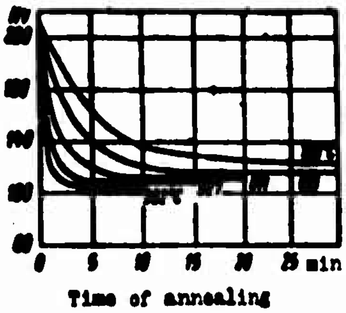


Fig. 45.

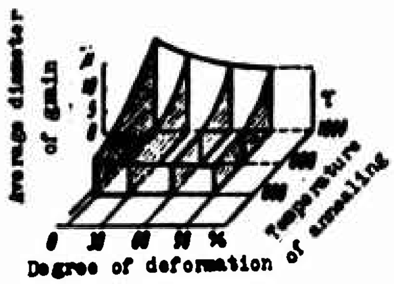


Fig. 46.

Fig. 45. Hardness of Monel depending upon time and temperature of annealing.

Fig. 46. Diagram of the recrystallization of Monel-metal (NMZhMts 28-2.5-1.5).

nickel, which at a temperature of hardening of 800-900°C, passes into a solid solution, but during subsequent tempering near 500-600°C, it again separates from it in a dispersed state.

Disintegration of a solid solution during tempering leave causes a significantly strengthened alloy. Alloy brand K after hardening, has σ_B = 70 kg/mm^2, δ = 40%, and after leave at 600°C σ_B = 115-130 kg/mm^2, δ = 20%, whereas Monel-metal without the addition of aluminum during δ = 20% has only σ_B = 80 kg/mm^2.

If, however, Monel-metal of brand K, after hardening deforms, then after tempering it attains $\sigma_B \approx$ 20 kg/mm^2 when $\delta \approx$ 5%.

A change of hardness of Monel K, depending upon the temperature of hardening is represented in Fig. 47.

When necessary, cold-deformed Monel-metal K is subjected to annealing at 870°C with subsequent cooling in water. In its annealed

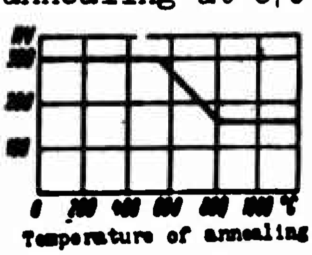


Fig. 47. Change of hardness of Monel K, depending upon temperature of hardening.

state Monel-metal K has σ_B = 63-75 kg/mm^2, δ = 25-45%, HB 140-180. Hardness of Monel-metal K, depending upon the time and temperature of annealing is shown in Fig. 48.

Nickel alloys are widely applied as heat-resistors. The basis of heat-resisting alloys EI437 and EI617 is nickel, which forms a solid solution with chromium, tungsten and molybdenum. Aluminum, titanium and boron with nickel, in the process of aging, form an excess intermetal phase. In the initial period of disintegration of a solid solution intermediate α'-phase will form on the basis of the combination $Ni_3(Al, Ti, Cr)$ with a grain-centered cubic grid, coherently connected with solid solution. In the case of prolonged aging at high temperatures (800-900°C) stable phases are formed: Titaniam nickel Ni_3Ti with hexagonal grid and Ni_3Al. Besides these phases, the formation of carbides and borides is possible. Alloys on a nickel basis have high heat resistance through the process of dispersion of hardening, along with the formation of intermetal phases, and the alloying of the solid solution by molybdenum and tungsten, increasing the durability of the interatomic binding and delaying process strengthening the alloy at high temperatures.

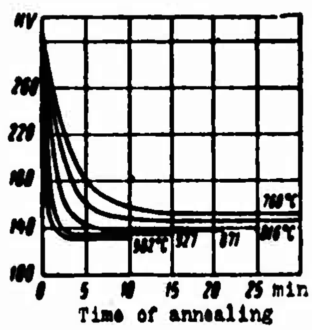


Fig. 48. Hardness of Monel K, depending upon time and temperature of annealing.

Heat treatment of alloy EI437 is produced under the following conditions: hardening at 1080 ± 10°C, time of holding of 8 hours, cooling in air; aging at a temperature of 700 ± 10°C, time of holding of 16 hours with subsequent cooling in air.

Double hardening is applied for alloy EI617:

1) at 1200°C (holding 2 hours with cooling in air);

2) at 1050°C (holding 4 hours also with cooling in air) and subsequent aging at 800°C for 16 hours, cooling in air.

Heating during hardening to higher temperatures is produced for changing into a solid solution the excess phases (carbides and intermetal type Ni_3Ti and others). Fast cooling fixes the supersaturated solid solution. Saturation of a solid solution by lay elements leads to a significant distortion of crystal grid, growth of stresses and splitting of blocks which, as a result, increases the resistance of plastic flow. During aging the excess phases separate from the solid state, where the hardness and heat resistance of an alloy increase. Singling out of excess phases increases heat resistance only under the condition of preservation of sufficiently high alloy capacity of solid solution. During a considerable impoverishment of a solid solution and an enlargement of the excess phase the heat resistance of alloy drops. Aging should be produced at temperatures, exceeding the operating temperature in conditions of exploitation.

Magnesium and Its Alloys

Technical magnesium. Technical magnesium mark Mg1 and Mg2 in the form of rods and sheets, in order to remove riveting and increase plasticity are subjected to annealing at a temperature of 340 ± 10°C for 30 min, with cooling in air. Annealed sheets have σ_B = 19 kg/mm^2, δ = 16%, HB 40.

Technical magnesium in its pure form is not used in machine building as structural material. But magnesium alloys are widely used both in the poured state, and also in the deformed.

Low-alloy alloys. Sheets from alloys MA1 and MA8, for the removal of riveting and an increase of plasticity, are annealed at a temperature of 320-350°C for 30 min with cooling in air. After annealing, sheets from alloy MA1 have $\sigma_B \geq$ 19 kg/mm^2, $\delta \geq$ 5%; from

alloy MA8 they have $\sigma_B \geq 23$ kg/mm^2 and $\delta \geq 14\%$.

For obtaining higher values of ultimate strength and yield point, annealing is produced at a temperature of 260-290°C for 30 min with cooling in air.

Average-alloy alloys. Sheets from alloy MA2 are annealed at a temperature of 250-280°C for 30 min with cooling in air.

Forgings and stamping from alloy MA3 are subjected to annealing at a temperature of 320-350°C for 4 hours with subsequent cooling in air.

After annealing, the alloy has $\sigma_B \geq 26$ kg/mm^2, $\delta \geq 8\%$, HB 50.

A diagram of recrystallization of alloy MA3 is shown in Fig. 49.

High-alloy alloys. The alloy of brand MA5 is annealed at a temperature of 350-380°C for 3-6 hours with cooling in air.

Forgings and stamping from alloy MA5 are subjected to after a 2-6 hour heating at a temperature of 410-425°C with cooling in air.

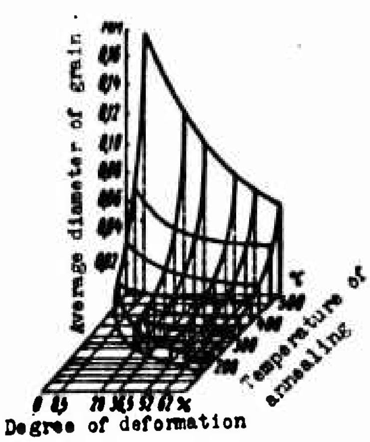


Fig. 49. Diagram of recrystallization of alloy MA3.

Hardening of alloy MA5 it is possible also with cooling in hot water (90°C). After hardening the alloy has $\sigma_B \geq 27$ kg/mm^2, $\delta \geq 6\%$, HB 55.

In order to obtain more hardness and the ultimate strength with a lowered plasticity after hardening, artificial aging is applied under the following conditions: heating for 8-16 hours at a temperature of 200°C with cooling in air. After such heat treatment σ_B is increased by approximately 2 kg/mm^2, δ drops by 2%.

Rods and profiles from alloy MA5 are subjected to artificial aging without preliminary hardening under the following conditions:

heating for 8-16 hours at a temperature of 175-200°C with cooling in air.

All semi-finished products from alloy VM65-1 are subjected to artificial aging without hardening at a temperature of 160-175°C with holding for 10-24 hours and with cooling in air.

Foundry magnesium alloys. Foundry magnesium alloys, for the removal of internal stresses, are subjected to annealing under the following conditions: alloy ML2 at a temperature of 200-250°C for 3-5 hours with cooling in furnace; alloys ML3, ML4, ML5, ML6 at a temperature of 170-250°C for 3-5 hours with cooling in a furnace.

Castings from alloys ML4, ML5, ML6 are strengthened by thermal treatment, and hardening with cooling in air at T4, hardening with subsequent aging at T6, hardening with cooling in water (90°C) and subsequent aging at T61.

Conditions of heat treatment and mechanical properties of these alloys are shown in Table 45.

During the heating of alloys for hardening, in order to avoid possible smelting of fusible compositions it is recommended that heating in two stages be conducted: preliminary heating at 330-340°C (alloy ML4), 360-370°C (alloy ML5), 350-360°C (alloy ML6) for 2-4 hours, and then an increase of temperature to that shown in the conditions.

Time of holding is undertaken without the calculation of the time of heating, but depending upon the mass of processed metal.

A characteristic peculiarity of heat treatment of magnesium alloys is their prolonged holding at a temperature for hardening and aging. The long duration of the operation of heat treatment is caused by the low speed of diffusion processes. This explains the

Table 45. Conditions of Thermal Treatment and Mechanical Properties of Foundry Magnesium Alloys

Brand of alloy	Form of heat treatment	Conditions of heat treatment			Mechanical properties		
		Temperature of heating in $^{\circ}C$	Time of holding in hours	Cooling medium	σ_B in kg/mm^2	δ in %	HB in kg/mm^2
ML4	Hardening T4	380 ± 5	8-16	Air	22	5	50
	Hardening and aging T6	380 ± 5 175 ± 5	8-16 16	Air Air	23	2	60
ML5	Hardening T4	415 ± 5	8-16	Air	22	5	50
	Hardening and aging T6	415 ± 5 175 ± 5 or 200 ± 5	8-16 16 or 8	Air Air	23	2	65
ML6	Hardening T4	410 ± 5	21-29	Air	22	4	60
	Hardening and aging T6	410 ± 5 190 ± 5	21-29 4-8	Air Air	23	0.5	65
	Hardening and	410 ± 5	21-29	Water at a temperature +90°C			
	aging T61	190 ± 5	4-8	Air	23	0.1	65

possibility of cooling details in air during hardening. It is not recommended that cold water be used during hardening, since during fast cooling in metal, large internal stresses appear sometimes leading to the formation of cracks.

Heat treatment of magnesium alloys is produced in a mine or chamber of electrical furnaces with an air medium. For preventing of fusion along the boundaries of grains of a solid solution and for an accuracy of automatic adjustment of the temperature of furnaces should be ensured in the limit of not more than ±5°C.

In view of the duration of the process of heat treatment of magnesium alloys and their inclination to oxidation, a protective atmosphere is applied, which usually is created with the help of the introduction, in a furnace, as much as 1% sulfurous gas or alloy in furnace of 3-4 kg of sulfurous cinder on 1 ton of metal. There are literature data about the good protective action from oxidation of magnesium alloys of carbon dioxide.

Heat treatment also may be produced in salt baths, consisting of a mixture of chrome salts.

THERMAL TREATMENT OF CASTINGS FROM CAST IRON

Heat treatment of an iron casting is used for giving it the required properties by means of changing the stage of strain, structure in the surface layers or in the volume during heating, holding and cooling, and also the chemical composition chiefly in surface layers of castings.

Peculiarities of processes of heat treatment of cast iron are determined by:

the preservation of the initial form of inclusions of graphite,

obtained in casting during its hardening and cooling in a form, and the change of only the quantity of graphite in the structure;

the obtaining in castings, and even in sections of the same casting, with an identical composition of cast iron, a complex of structures sharply distinguished among themselves, depending upon the metallurgic process of smelting cast iron, the technology of manufacture of the form and construction of castings.

In accordance with these peculiarities, the region of application of heat treatment of cast iron is limited by the products, in which the known methods of metallurgical and technological process turn out to be insufficient for obtaining the required phase composition and structure of cast iron in casting (casting from wrought iron and, in a very large part, from highly durable cast iron).

In the production of castings from gray cast iron, heat treatment has a very limited application, mainly for changing the state of strain, partial graphitization in the surface layers, changing the hardness and so forth.

A basic parameter, determining the form and conditions of heat treatment of cast iron, is, in contrast to heat treatment of steel, not its chemical composition, but chiefly the initial and final phase composition and structure.

Wrought iron. Heat treatment of castings from white cast iron in production of ductile — graphite annealing — is a basic operation of the technological process, along with the operations of the smelting of cast iron and formalization of casting, and is intended to obtain in it a ferrite structure of basic metallic mass and graphite of flaky, compact form, unattainable with any other methods.

In the process of the heat treatment of white cast iron a radical change of its phase composition and structure occurs, as a result of full or partial graphitization or graphitization with simultaneous decarbonizing, and cast iron from hard and fragile becomes, within definite limits, plastic and well processed.

The processes of heat treatment are applied most frequently, in which full graphitization of white cast iron is carried out and as a result ferrite wrought iron is obtained.

For obtaining of castings with a higher durability with less plasticity of cast iron, the process of graphitization is not conducted to full completion and a perlite structure of the basic metallic mass is attained. During annealing with a simultaneous decarbonizing the process of graphitization is carried out in an oxidizing medium, this is accompanied by a removal from the casting of a significant part of the carbon and as a result perlitic wrought iron is obtained, which is white centered.

Graphitization of white cast iron in the production of ductile is attained in two stages. In first stage full decomposition of the primary and secondary cementation is carried out; in the second stage full or partial decomposition of eutectoid is cemented, depending upon the brand of cast iron (Fig. 50). During heating, the intermediate and final cooling of castings, corresponding to the stage of process of graphitization also obtain certain development, but actually their value is determined by the characteristic of thermal furnaces.

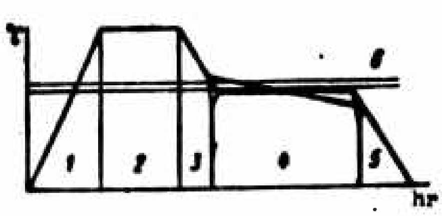


Fig. 50. Diagram of the temperature rate of heat treatment of ferrite wrought iron: 1) heating; 2) first stage of graphitization; 3) intermediate stage of graphitization; 4) second stage of graphitization; 5) cooling; 6) critical interval.

Graphitization of the primary and secondary cementite is attained during heating and holding of castings higher than the stagnation temperature.

For graphitization of eutectoid cementite it is necessary to have delayed cooling in the interval of eutectoid transformation. Since, with an increase of temperature the heating and holding period of disintegration of primary and secondary cementite is sharply reduced (Fig. 51), the first stage of graphitization is carried out the highest temperatures, allowed by the construction of the furnace and limited by increasing the deformation and oxidation of castings. The optimum temperatures of the process are actually within limits of 950-1050°.

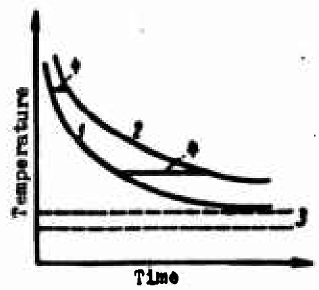


Fig. 51. Kinetic curve of the beginning and end of the right stage of graphitization: 1) beginning of graphitization; 2) end of graphitization; 3) critical interval; 4) periods of disintegration of cementite.

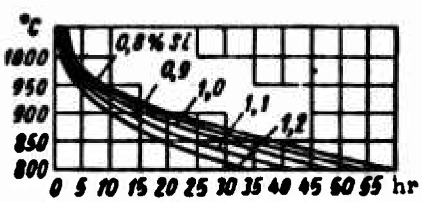


Fig. 52.

The duration of holding, in the first stage of graphitization, depends mainly on the content of silicon in white cast iron (Fig. 52), speed of cooling of casting in the form (Fig. 53), thickness of sections of casting (Fig. 54) and partly on the temperature of heating of the liquid during melting (Fig. 55).

With the deflection of the content in cast iron of sulfur and manganese from equilibrium, the duration of the process sharply increases; with a content in the cast iron of chromium above 0.06-0.07%, full graphitization in the conditions of industrial conditions of heat treatment is practically unattainable.

The second stage of graphitization is carried out during the cooling of castings in the interval of temperatures of eutectoid transformation, actually within the limits of 760-720°, with an approximate speed of 2-5° in 1 hour. An increase of holding, in the first stage of graphitization, above that necessary, causes a reduction of quantity and growth of dimensions of inclusions of graphite, an increase of methods of diffusion of carbon and lengthening of the second stage.

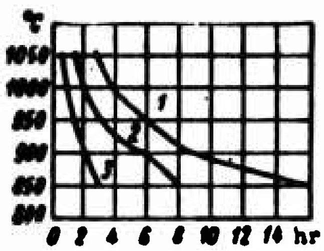


Fig. 53.

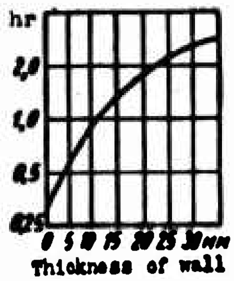


Fig. 54

Fig. 53. Influence of speed of cooling casting on the duration of graphitization: 1) during casting in earth; 2) during casting in a chill mold; 3) during preliminary hardening at 950°.

Fig. 54. Influence of the temperature of melting on the duration of graphitization.

The heating of castings is carried out usually with the maximum speed, allowed by the construction and capacity of furnace.

The process of final cooling of castings is conducted only by two conditions — by means of slow cooling with a furnace to 200-300° or fast cooling in air with average speed, exceeding 100° in 1 hour. During delayed cooling to 450° and its further acceleration on the surface of grains of ferrite, carbides can be separated (white break), and, as a result, cast iron completely loses shock viscosity.

The stabilization of industrial conditions of heat treatment in the production of ferrite wrought iron and compensation of deflections from chemical composition which exist, is attained by treatment of the melted substance in a distributing ladle by the addition of aluminum in the quantity 0.5-0.3%, assimilated by cast iron in insignificant quantity in the form "of traces." During the accumulation in cast iron, through the use of returns of a unique product of

aluminum over 0.03% (by results of chemical analysis), these returns have to be excluded from charge materials.

Among the very effective methods of acceleration of the process of graphitization, tested and utilized in industrial production of wrought iron, are the following:

1. Sharp reduction of the duration of the first stage of graphitization by means of increasing the temperature to 1050-1060° and the acceleration of heating, carried out in electrical salt baths (Fig. 56) with 75% barium chloride and 25% sodium chloride.

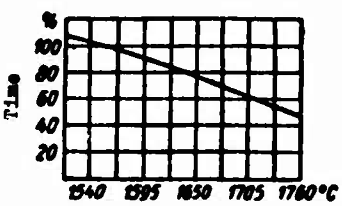


Fig. 55.

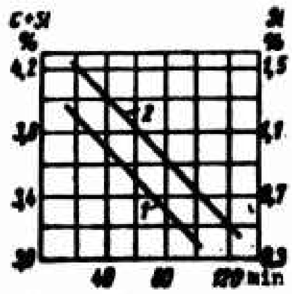


Fig. 56.

Fig. 55. Influence of the temperature of melting on the duration of graphitization.

Fig. 56. The duration of the first stage of graphitization during annealing of the white cast iron in salt bath at 1050-1060°: 1) content of Si%; 2) (C + Si)%.

2. A modifying treatment of meltings of cast iron before pouring is the addition of alloys or mixtures in the ladle of the following composition (Table 46). Besides a sharp reduction of the cycles of heat treatment, a modification of meltings by composition of 1-5 prevents the separating out of primary graphite in thermal units of castings, but a compositions 1.3 and 5 ensures full graphitization of castings from cast iron with an increased content of chromium to 0.1%. The treatment of melted magnesium allows the application of wrought iron for castings with a significantly larger thickness.

3. Holding of castings, during heating, in an interval of temperatures of 250-450° for 3-5 hours.

Table 46. Composition of Aftercharges

No composition	Components in % to weight of melting				
	Bi	B	Al	Sb	Mg
1	0.002-0.004	0.002-0.004	—	—	—
2	0.002-0.004	—	0.015-0.03	—	—
3	0.002-0.004	0.002-0.004	0.015-0.03	—	—
4	0.002-0.004	—	—	0.004-0.007	—
5	—	0.002-0.004	0.005-0.02	0.004-0.007	—
6	—	—	—	—	0.2-0.5

4. Preliminary hardening of castings before heat treatment in water or oil at 950-970° with holding for 0.75-1.0 hours.

This method will be applied for simple castings with a limited thickness, allowing hardening without the formation of cracks.

Industrial conditions of heat treatment of wrought iron with reference to furnaces of different constructions are given in Table 47.

For the protection of castings from oxidation and deformation in the process of prolonged heat treatment during high temperatures they are packed in cast or welded boxes, gathered in cast or welded boxes, gathered in piles with tightly smeared joints, with sand filled in the intervals between castings. In electroannealing furnaces the packing of castings is applied only for their reliable installation on a trolley, without filling by sand.

The most rational type of furnace for heat treatment in the production of wrought iron is the methodical furnace with electric or radiation heating, neutral atmosphere, with load of castings having small parties, disposed on pans or in grids. Losses of time during the heating and cooling of castings in such a furnace are less with

a larger homogeneity of conditions of heat treatment for every casting, regardless of the location distribution in the furnace.

However, in plants, for the heat treatment are applied ardent annealing furnaces with a sliding hearth or methodical furnaces of continuous action with moving trolleys or pans along the furnace.

Chamber electroannealing elevator furnaces can be specialized for carrying out of one of the two stages of heat treatment. In this case the unit consists of two furnaces — high temperature and low-temperature, disposed on one axis with general loading and unloading devices. Such a specialization of furnaces, requiring rhythmical work, is applied under conditions continuous-mass production and has economic advantages.

Heat treatment in the production of perlitic wrought iron is characterized by incomplete graphitization of eutectoid cementite, but for its special brands there is an increase of concentration of carbon in solid solution and the formation metastable structures of basic metallic mass.

Conditions of heat treatment in the production of perlitic wrought iron, depending upon the required structure, are schematically represented in Fig. 57, II-V in comparison with the conditions of the heat treatment of ferrite wrought iron (Fig. 57, I).

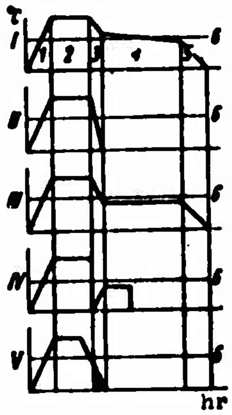


Fig. 57. Diagram of heat treatment of perlitic wrought iron: the designation is the same, as on Fig. 50.

The limitation of heat treatment with the full completion of the first stage of graphitization, as it was shown on Fig. 57, II, characterizes the conditions for obtaining perlitic wrought iron with structure graphite + laminar perlite.

Table 47. Industrial Conditions of Heat Treatment in the Production or Ferrite Wrought Iron

Plant	Type of furnace	Regime											Modifier
		Heating				I Stage		Intermediate stage		II Stage			
				Including delayed									
		Temperature in °C	Time in hours	Temperature in °C	Time in hours	Temperature in °C	Time in hours	Temperature in °C	Time in hours	Temperature in °C	Time in hours	General duration in hours	
Mos ZIL	Elevator electrical resistance............	20-970	29	350-400	6	970-900	10	900-740	1	740-720	12	52	Al
The same	The same...............	20-970	15	–	–	970-950	6	950-730	1	730-710	10	32	Al + Bi + B
The same	Tunnel gas.............	100-970	18	–	–	970-900	12	900-750	18	750-730-600	8 + 9.5	64.5	Al
The same	The same...............	100-1050	18	300-430	6	1050-900	11	900-760	1.5	760-720-630	11 + 1	43.5	Al + Bi + B
GAZ	Elevator electrical resistance............	20-900	20	350-420	6	900-970-920	10	920-750	1	750-740	12	43	Al
The same	The same...............	200-970	15	–	–	970-950	3	950-750	1	750-740	2	21	Al + Bi + B
Lepse plant	Tunnel black oil.......	200-990	7	–	–	990-1020	14	1020-730	12	730-690-630	19 + 7	54	Al
Rossel'mash	Tunnel gas.............	200-1000	12	350-400	4	1000-1020	5	1020-850	1	850-620	13	31	Al
Ukhtomskiy plant	Tunnel black oil.......	200-1010	25	–	–	1010-990	23	990-750	12	750-730-480	10 + 22	92	Al
Kosogorskiy plant	Elevator electrical resistance............	100-950	26	–	–	950-920	8	920-745	4	745-720	7	45	Al
Taganrogskiy combine plant	Methodical electrical resistance............	100-960	10	–	–	960-900	4	900-760	10	760-720	12	36	Al
The same	The same...............	100-1000	8	350-400	3	1000-950	4	950-800	4	800-720	8	24	Al
"Borets" plant	Salt bath with electro-heating....	20-1060	1	–	–	1060	2	1060-760	1	760-650	8	12	–
	Chamber gas...........	20-400	1	400	6	1060	1	1060-760	1	760-720-650	4	13	–
Boykov plant	Chamber gas............	200-950	25	–	–	950-970	10	970-790	9	790-670	11	55	–

If to this conditions the holding of a casting is added at a temperature lower than the critical interval (Fig. 57, III), coagulation of perlite is attained and wrought iron is obtained with a structure of graphite + granular perlite.

Hardening of cast iron after the finish of the first stage of graphitization and subsequent tempering at a temperature lower than the critical interval (Fig. 57, IV) characterize the conditions for obtaining wrought iron with a structure graphite + solid solution with a higher concentration of carbon — from sorbite to martensite.

Finally, the condition on Fig. 57, V, limited by incomplete graphitization of the primary and secondary cementite, is characterized for obtaining wrought iron with the structure of graphite + + cementite + perlite.

For cast iron, alloyed with elements, forming stable carbides Cr, W, V, the obtaining of this structure is attained by model conditions of heat treatment, established for ferrite wrought iron.

In industrial conditions it is difficult to obtain large parties of uniform castings of perlitic wrought iron in furnaces of usual type because of the impossibility of precisely executing conditions of cooling for all castings in the settlement of a furnace. Therefore, more reliable results are attained by the normalization or hardening, with tempering, of castings of ferrite wrought iron.

An exemplary condition of normalization is the holding of a casting for 0.5-1 hours at 850-900° with subsequent tempering at 650-700° for 1-2 hours. Hardening is produced at the same temperature as normalization.

Maximum hardness during the hardening of ferrite and ferrite perlitic cast iron is attained while holding at the interval of these temperatures for 60-120 min (Fig. 58). The influence of the

temperature of hardening in water on the hardness of hardened ferrite cast iron is shown on Fig. 59.

Directly after hardening the castings possess high hardness and are very fragile. The regulation and achievement of the required mechanical and exploitational properties is attained in the process of tempering, carried out by heating the castings to 650°, with holding depending upon the final structure.

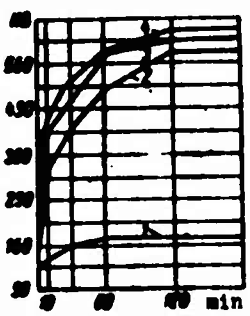


Fig. 58. Change of hardness of ferrite wrought iron depending upon holding at different temperatures of hardening: 1) 760°; 2) 800°; 3) 850°; 4) 900°.

The conditions of heat treatment of perlitic cast iron are made precise by experimental means with a determination of the time, necessary for the achievement of a fixed degree of graphitization.

Operations of surface hardening with heating by acetylene oxygen flame or currents of high frequency may be applied to castings of wrought iron in the absence or limited development of a surface decarbonized layer.

Surface hardening of details of wrought iron with heating by currents of high frequency is conducted to achieve high surface hardness and resistance to wear and their general durability. The most widespread conditions of surface hardening are with heating to 1030-1070° for 6-8 sec or to 1100-1150° with holding 50-100 sec, with water cooling in both cases. Low tempering may be combined with the operation of hardening.

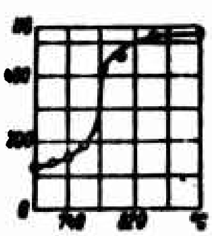


Fig. 59. Influence of the temperature of hardening in water on hardness of ferrite wrought iron.

Heat treatment in the production of decarbonized wrought iron differs by conducting the process in an oxidizing medium, with the

packing of the castings in a mixture of 25% fresh iron ore with 75% return from the mixture of the preceding cycle.

The lowered heat capacity of the packing material and the inevitable significant increase of general settlement extend to 120-140 hours the operation of heating and cooling during heat treatment for obtaining decarbonized wrought iron. The optimum temperature of the treatment is 950-1050° with holding for 30-40 hours. Production of such cast iron in connection with the uneconomicness of the process has practically ceased everywhere.

For restoration of the shock viscosity of wrought iron, lost during deviations from conditions of cooling castings after annealing and the liquidation of white break, castings are heated to 650-720°, and held for 1 hour to 25 mm of thickness and cooled in air.

Highly durable cast iron with spherical graphite. The heat treatment of castings from highly durable cast iron is determined by the properties of its phase constitution and structure.

Analogous to wrought iron, the basic base brand of highly durable cast iron is ferrite cast iron, the obtaining of which must be done with full graphitization of the primary and secondary cementite, in order to reliably avoid the formation which is not possible during the hardening of castings in a form, with the exception of castings with sections of very large dimensions.

Analogous to steel, the mechanical and exploitational properties of highly durable cast iron are determined by its phase structure and the structure of the basic metallic mass, since the weakening action of inclusions of graphite is limited approximately by their total fractions in area of a casting section, and mainly their value as concentrators of stresses is insignificant in comparison with inclusions of laminar graphite in gray cast iron.

As a result, a lowering of the content of carbon in highly durable cast iron does not have such value, as in steel, ductile and gray cast iron, and, moreover, its increase, as well as the content of silicon is one of basic methods of the improvement of the foundry properties of highly durable cast iron and obtaining qualitative castings.

In accordance with these peculiarities heat treatment of castings of highly durable cast iron is like heat treatment in the production of castings from ferrite wrought iron by the obligatory operation of a technological process, and the heat treatment is analogous to the heat treatment in the production of castings from ferrite wrought iron by the obligatory operation of a technological process, but a heat treatment analogous to the heat treatment in the production of castings of steel is used for achieving the required constructional and exploitational properties and all form of corresponding processes are applicable in the production of castings of highly durable cast iron.

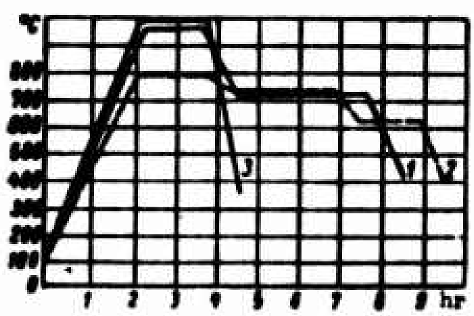


Fig. 60. Conditions of heat treatment: 1) high-temperature graphite annealing; 2) low-temperature graphite annealing; 3) graphite normalization.

Basic forms of graphite heat treatment are (Fig. 60): annealing for the decomposition of the primary and secondary cementite 1, low-temperature annealing for the decomposition of eutectic cementite 2 and normalization 3. The last one can be applied for the normalization of details after the machining of castings.

The conditions of all these processes, developed in reference to the treatment, in production, of castings from wrought iron and common carbon steel, can be used in principle also for the treatment

of castings from highly durable cast iron.

However, the specific composition of this cast iron, the presence of phase components, absent in steel or assisting in wrought iron in other quantities, require the introduction of several changes.

With analogous qualitative regularities of heat treatment, with phase and structural transformations in highly durable cast iron with ductile, the peculiarities of transformations and conditions related to the influence of a higher content of a series of elements on the stability of cementite and the position of critical points mainly of silicon, manganese and phosphorus.

Silicon particularly affects the position of the critical points during heating and cooling of cast iron (Fig. 61). The influence of manganese and phosphorus is shown on Fig. 62 and 63.

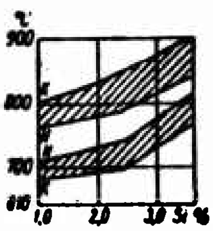


Fig. 61.

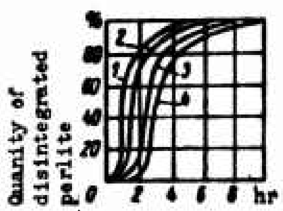


Fig. 62.

Fig. 61. Influence of the content of silicon on the position of the critical points during heating and cooling of cast iron. H — beginning of the transformation; K — end of transformation.

Fig. 62. Influence of manganese on the disintegration rate of eutectoid cementite. Composition of cast iron: 1 and 2) 3.2%C; 2.9% Si; 0.47% Mn; 3 and 4) 32% C; 2.87% Si; 0.75% Mn. Temperature of annealing: 1 and 3) 740°; 2 and 4) 700°.

Graphite annealing 1 (see Fig. 60) is used for obtaining a ferrite structure of cast iron during the presence at the beginning of primary and secondary cementite. With a perlite-ferrite structure the obtaining of ferrite cast iron is ensured by the treatment of condition 2. Condition 3 is used for obtaining a perlitic structure of basic metallic mass with a content of ferrite to 10%; during cooling in air from temperatures of 850-750° different relationships of contents of perlite and ferrite are obtained.

An increase of the temperature of graphite annealing to $1020\text{-}1050^{\circ}$ is effective for castings from highly durable cast iron with a thickness of walls to 50 mm, for their full protection from oxidation, for instance, in a salt bath. Furthermore, the first stage of graphitization is completed approximately after 0.5 hours, and the second is conducted in an electro-heating furnace, — for 0.75-1 hours.

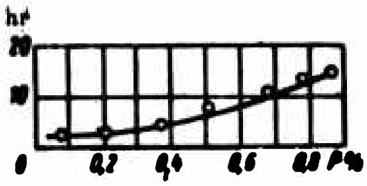


Fig. 63. Influence of phosphorus on the duration of full graphitization of eutectic cementite at 740°.

Conditions of the final cooling of castings from highly durable cast iron are analogous with regular wrought iron, and during an incorrect passage of interval $650\text{-}450^{\circ}$ a full loss of shock viscosity by highly durable cast iron is possible. Its restoration is attained by treatment with conditions, general with the conditions for castings from wrought iron.

Normalization of articles and details for the purpose of increasing their hardness, durability and resistance to wear is conducted by conditions depending upon the required quantity of perlite (Fig. 64).

Spheroidization of perlite is attained by holding at a temperature lower than the critical castings from cast iron, containing not more than 5.4-5.6% carbon and silicon and heightened quantities of stabilizing perlite of elements, mainly manganese to 1.0-1.5%.

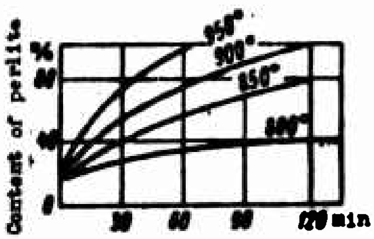


Fig. 64. Influence of temperature and time of holding on the quantity of perlite during the normalization of highly durable cast iron with 3.0% C; 2.85% Si; 0.7% Mn; 0.25% P.

Conditions of volume hardening of articles and details, which exceed graphite annealing, are characterized by delayed heating due to the great inclination of

highly durable cast iron to the formation of internal stresses and its small thermal conduction. The maximum temperature of heating under hardening increases with an increase of the content of silicon and is within the limits of 880-920°. The time of holding constitutes approximately 1 hour for every 25 mm of thickness of section of casting. Articles and detail of simple configuration harden in water; complicated configurations harden in oil.

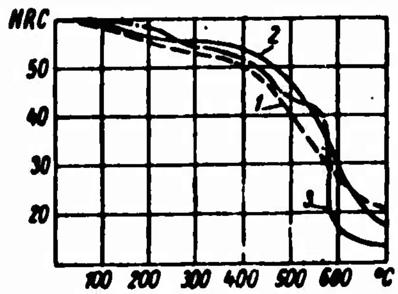


Fig. 65. Influence of temperature of tempering on the hardness of highly durable cast iron: 1) 2.63% Si; 2) 3.3% Si; 3) 4.03% Si.

The given hardness and its durability and plasticity of cast iron after hardening are attained by tempering (Fig. 65); the time of holding is lowered with an increase of temperature from 1-4 hours at 400° to 1-2 hours at 500-600°.

During isothermal hardening the optimum temperature with a content of silicon of 3.0-4.0% is near 900°; holding 15-60 minutes. The optimum temperature of the tempering medium for obtaining a uniform structure from troostite and 25-30% residual austenite is 300-350°. Isothermal hardening can be applied for articles and details with a thickness to 30 mm, with a large relationship between surface and volume (for bushings, cylinders and so forth).

Surface hardening with heating by an acetylene oxygen flame and high frequency currents is effective only for cast iron of perlitic and perliteferrite structure, with a quantity of ferrite, not exceeding 30%. The temperature of hardening during heating with currents of high frequency reaches 1100°. Conditions of heating have to ensure a saturation of austenite by carbon of inclusions of graphite only to a given depth.

Nitration of articles and details from highly durable cast iron is very effective for increasing their longevity and reliability in exploitation through an increase of resistance to wear, fatigue durability and corrosional stability, in connection with the special conformity of the phase composition and the structure of cast iron to this treatment. The optimum temperature of the process is near 650°, holding for 3-4 hours. Uniform hardness of a nitrated layer is attained only with ferrite of the initial structure of cast iron (Fig. 66).

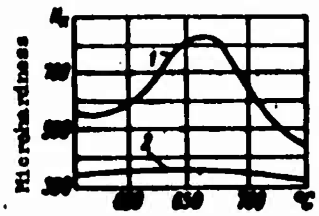


Fig. 66. Dependence of microhardness on the temperature of nitration: 1) highly durable cast iron; 2) steel; holding — 1 hour.

Remaining forms of the chemical-heat treatment of castings and details from highly durable cast iron with spherical graphite sulfiding, calorizing, during enameling and others are analogous to process of the heat treatment of castings of steel.

<u>Gray iron</u>. Heat treatment of castings from gray cast iron is applied chiefly for the improvement of technological and exploitational properties, workability, resistance to wear and so forth, as an operation of an additional treatment of incidental parties of castings with special properties or for the correction of a part of castings, obtained with deviations from the required quality.

Such a limited value of heat treatment is determined, first of all, by the possibility of obtaining the required properties by methods of technology of foundry production and the direct dependence of mechanical properties of gray cast iron on the content of carbon, form, dimensions and mutual location of inclusions of graphite, the possibility of essential change of which, after the hardening of the casting is completely excluded.

Besides this, even a limited influence on the phase composition and structure of its basic metallic mass is hampered by processes of incidental graphitization, which is caused by the content in cast iron of heightened quantities of silicon.

Graphite annealing is used for castings, in surface layers of sections or in the whole volume of which the inclusion of primary and secondary cementite assist.

Full graphitization of these inclusions, forming frequently in the surface layers of castings during the use of metallic forms, is finished at a temperature of 850-900° for 0.5-1.0 hours. Graphitization in the volume of castings is attained at a temperature of 900-950° for 0.5-5.0 hours depending upon the quantity of inclusions of cementite, chemical composition and dimension of the sections of castings.

The possibility, during the laminar form of graphite, of applying very high temperatures of heating — to 1100-1125° allows the fulfillment of graphite annealing in salt baths for several minutes (Fig. 67) and with heating by currents of high frequency for several seconds.

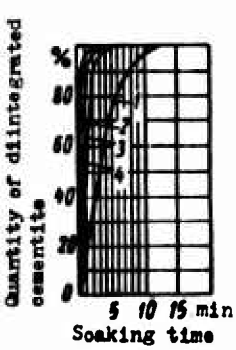


Fig. 67.

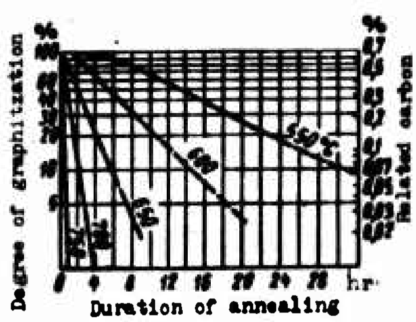


Fig. 68.

Fig. 67. Dependence of disintegration of cementite in gray iron on the time of holding and the temperature of heating in salt baths at: 1) 1050°; 2) 1100°; 3) 1125° and 4) 1150°.

Fig. 68. Influence of temperature and duration of annealing of gray cast iron on the degree of graphitization (quantity of connected carbon).

Low-temperature graphite annealing used to decrease hardness for the purpose of improving the workability by cutting of castings from gray cast iron, not

satisfying the requirements due to deviations from the technological process, or for obtaining of a purely ferrite structure of basic metallic mass in cast iron with a limited content of silicon.

The dependence of the degree of graphitization of eutectoid cementite of gray cast iron, containing near 2.5% silicon, on the temperature of heating and time of holding during annealing is shown in Fig. 68.

Decarbonizing annealing is applied in the production of castings of gray cast iron, covered by acid-resistant enamels for the removal from the surface layer of carbon and gases and the prevention of the formation, in enamel, of distendings and bubbles. The temperature of annealing is 850-900° with holding for 15-40 min and cooling in air.

Normalization is used for articles and details from gray cast iron with a ferrite or ferrite perlitic structure of basic metallic mass for increasing its quantity of eutectoid cementite and, as a result, for increasing hardness.

The dependence of the quantity of perlite in the structure of gray iron on the content of silicon and the temperature of the process is shown in Fig. 69; usually, normalization is conducted at 850-950° with holding for 1-2 hours.

This process is hampered by the necessity of intense cooling of castings for the prevention of the formation of significant quantities of ferrite in the form of edgings for the inclusions of graphite.

Volume and surface hardening of articles and details of gray cast iron is applied during a perlitic structure of the basic metallic mass for an increase of hardness and resistance to wear and production at a temperature higher than the interval of eutectoid transformation.

The peculiarity of the process of heating during volume hardening of castings of gray cast iron is a necessity of the essential acceleration, starting from a temperature of 500-550°, for the purpose of preventing the process of incidental graphitization. Holding for heating is determined depending upon the thickness of a section of figuring 1 hour for 25 mm of maximum thickness, and also depending upon the initial structure of cast iron: 10-15 min for perlitic cast iron and 1.5-2.0 hours for ferrite.

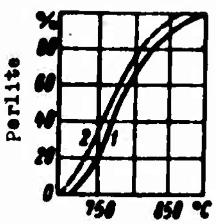


Fig. 69. Dependence of the quantity of perlite in gray cast iron on the temperature of normalization with 1) 3%Si; 2) 2.1%Si.

Articles and details of simple configuration harden in water, those of complicated configuration harden in oil. During hardening with interrupted cooling by means of extracting castings from a tempering medium at 150-200°, the dynamic durability of cast iron increases.

Final forming of mechanical exploitational properties is attained during the tempering of hardened cast iron.

The influence of the temperature of hardening on the hardness of different forms of cast iron is shown in Fig. 70.

During isothermal hardening of articles and details from gray cast iron with limited dimensions of sections — to 15-20 mm, the temperature of heating is taken at 850-900°, with holding for 0.25-1.0 hours. Used as tempering media are saltpeter, alkali and in certain cases of oil at temperatures of 250-320°. The lower limit corresponds to conditions of obtaining a predominant martensite structure; upper for obtaining a structure of needle troostite. The time of holding in isothermal medium is 20-60 minutes.

Surface hardening with heating by high frequency currents is used for details from modified perlitic gray iron. The depth of a hardened layer depends on the frequency of current and increases with its decrease and increase of capacity and time of heating.

For obtaining a structure of thin-needle martensite, the optimum parameters of the process are the following: specific power 1.0 kilowatt/cm^2, time of heating 6-8 sec, gap between inductor and is detailed 3-4 mm. With a capacity of more than 2.0 kilowatt/cm^2, gap, smaller than 1.0-1.5 mm, the surface of the detail is fused with the formation of cementite eutectic.

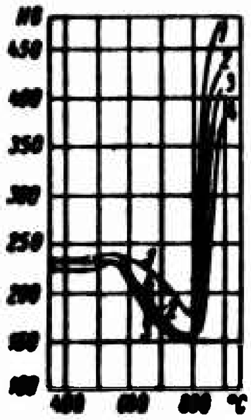


Fig. 70. Influence of the temperature of hardening on the hardness of gray iron: 1) alloy cast iron; 2 and 3) unalloyed cast iron; 4) phosphorous cast iron.

Nitration is used for finally treated details from gray cast iron, alloyed the same as steel, chromium, aluminum and molybdenum for increase of hardness, resistance to wear and corrosional stability, and is carried out at 520-560° in a medium of dissociating ammonia for 60-90 hours. For anticorrosive nitration of articles from usual unalloyed cast iron, used in a humid atmosphere, the temperature is increased to 550-700°, and holding is reduced to 0.5-1.0 hours.

Heat treatment for the stabilization of stresses. Heat treatment for the stabilization of stresses in castings from cast iron is intended for preventing their warping during treatment and exploitation in machines and equipment and is most effective in combination with processes of alloying.

The magnitude of residual stresses, appearing during cooling of casting and provoking its warping, is determined, basically. by the character of cooling in the interval of temperatures of transition of cast iron from plastic into an elastic state.

Stresses are created as a result of a temperature drop between the thick and thin sections of a casting and by the section of its walls between their internal sections and the surface, during deviations of a change of temperature from a strictly linear law, along any coordinate of axis, lying in this section.

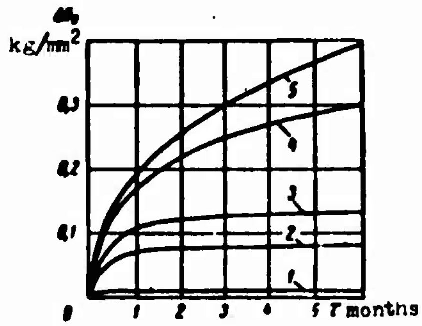


Fig. 71. Character of the reduction of initial stress — 10 kg/mm² with flow of time in casting from: 1) steel; 2) highly durable cast iron; 3) from ferrite wrought iron of brand KCh 35-10; 4) cast iron of brand SCh 35-56; 5) from cast iron of brand SCh 21-40.

Besides this, residual stresses appear as a result different coefficients of temperature expansion during chemical and structural heterogeneity of cast iron in casting.

During machining of castings with a removal of significant layers of metal with residual stresses and a relaxation after a time, these stresses are redistributed and cause repeated warping of castings.

In castings from cast iron a relaxation of residual stresses takes place mainly through a reduction in places of concentration — for inclusions of graphite — and during a laminar form of inclusions is especially significant. On Fig. 71 are given the curves of change after a time, of residual stress in casting with its identical initial magnitude — 10 kg/mm^2.

For castings of cast iron with laminar graphite it is not only significantly greater, but disappears more slowly in time.

The process of warping of castings of cast iron is changed in time and, independent of the brand of cast iron and magnitude of initial stresses from 1 to 14 kg/mm^2, practically ceased after 12 months, where the main part (near 70%) warping occurs during first three months (Fig. 72).

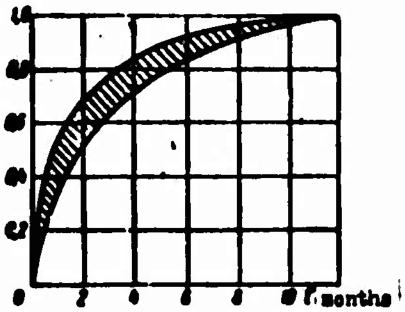


Fig. 72. Change of relative magnitude of warping, with the flow of time, for cast iron of different brands from SCh 12-28 to SCh 35-56.

With an increase of the initial stress, warping of castings increases for all brands of cast iron (Fig. 73). With an identical initial stress, warping of castings from more durable cast iron is significantly less (Fig. 74).

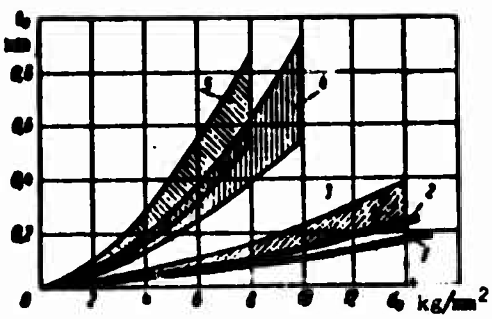


Fig. 73. Warping from relaxation after 12 months of initial stresses from cast iron: 1) SCh 35-56; 2) SCh 32-52; 3) SCh 21-40; 4) SCh 15-32 and 5) SCh 12-28.

But since the magnitude of residual stresses in casting from cast iron depends on the indices of its durability and increases with its increase (Fig. 75), then the total action of both factors determines the practical independence of relaxation of residual stresses and warping of casting on the brand of cast iron.

The magnitude of warping of castings essentially depends on their bend rigidity and is reduced with its growth. Therefore, for stopping actually noticeable warping of rigid castings, aging for 6 months is frequently sufficient, whereas for small-rigid castings, not less than 9-12 months is required. Moreover, in the process of relaxation,

residual stresses after 12 months are lowered by approximately 4-6%, but warping of castings is stopped, and the absolute value of residual stresses in casting from cast iron cannot be a criterion of its possible warping.

During natural aging castings from cast iron undergo rough machining, are held for 3-6 months, pass through the operation of semifinished treatment and again are held for 4-9 months, depending upon bend rigidity; during finishing operations layers of metal are removed, the thickness of a millimeter.

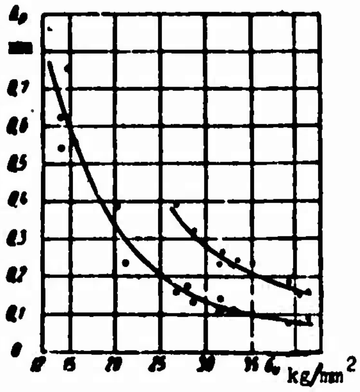


Fig. 74. Warping of various cast irons vs. bending strength σ_0: 1) $\sigma_0 = 8$ kg/mm^2; 2) $\sigma_0 = 14$ kg/mm^2.

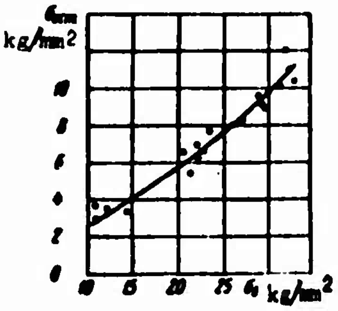


Fig. 75. Dependence of the magnitude of residual stresses in samples of different cast iron — from SCh 12-28 to SCh 35-56 — on the ultimate strength for extension.

Low-temperature annealing of ion casting is produced at a temperature of holding near 550° for 3-4 hours. In order to avoid residual stresses cooling to a temperature of 400-350° is conducted at a speed of not more than 10-20 deg/hr. Furthermore, it is necessary to consider the possibility of preservation after annealing, in iron casting of complicated configuration, significant residual stresses, which, during subsequent machining of castings, are redistributed and may cause warping. Therefore, after rough machining, low-temperature annealing and subsequent semifinished treatment of casting of small-rigid details, it is necessary to subject, before finishing treatment, to aging of not less than 3 months. Very effective methods of stabilization of residual stresses in casting and removal of their subsequent warping are methods of aging

with the help of vibration, ultrasonics, and also static load of castings or their load with help of temperature stresses (in the stage of assimilation).

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CHAPTER V

ELECTRICAL, CHEMICOMECHANICAL AND ULTRASONIC METHODS MATERIALS TREATMENT

Electrical and chemicomechanical methods of treating materials, as well as ultrasonic methods, at the present time represent an extensive and independent division of technology which is being strenuously developed in connection with appearance and development of new fields of technology and industry (nuclear and missile engineering, electronics, etc), associated with the application of new complex methods of treating, materials.

The basic and most important information for machine building using the corresponding conditional designations and abbreviations are given in Table 1. The legend for these designations is given in auxiliary Tables 2-8.

ELECTRICAL METHODS

Electrical methods are those methods of treating materials in which breakdown and removal of a substance, its transfer, deformation or structural transformations, etc., occur as a result of introducing electrical energy directly in the zone of treatment without intermediate, preliminary transformations of this energy into other forms (for instance, as in mechanical treatment).

Table 1. Basic Technological and Technical Economic Characteristics of Electrical and Chemical-Mechanical Methods of Treatment

Operation	No. figure in text (conditional designation of method)	Effectiveness of operation according to Table 7 (degree of mastering)*	Operating voltage in v	Density of current in a/cm^2	Specific power consumption kw-hr/kg	Speed of tool movement in m/sec	Wear of tool in %	Material of tool (in Table 5)	Shape of tool (per Table 4)	Shape of parts (per Table 3)	Basic processed materials (per Table 2)	Equipment (per Table 6)	Precision per GOST, class	Speed removal of metal in $\frac{mm}{min}$	Speed removal of metal in $\frac{mm^3}{min}$	Purity of treated surface, class per GOST 2789-59	Composition of medium (per Table 8)
Cutting on contour of plane parts from sheet with band saw	2c (AM)	9; 1; 5 (PP)	20-30	75-500	3-5	15-30	-	1; 2; 3	8	6	1; 18	22	2-3	-	1500-4000	2-4	13
Cutting on contour of flat parts . . .	5d, 5e (KIS)	9; 1 (PP)	60-150	-	-	-	-	-	-	3; 4	1; 18	7; 8	2-4	-	70-300	2-3	10; 11
	(KIM)	1; 4; 7; 10(P)	-	-	-	-	-	-	-	3; 4	2; 11	3	2-3			2-5	15
Polishing of metallic surfaces .	1f (EKh)	1; 2; 3; 4 (P)	ferrous 10-15	0.3-0.4	10-30	0.0	0.0	4; 5; 7	1	6	3; 4	1; 2	2-3	7-10		1-2 classes higher than initial	1
			nonferrous 5-7	0.1-0.5	5-20	0.0	0.0	4; 5; 7; 1; 15	1	6	1; 2; 8; 15	1; 2	2-3	3-5			
Polishing of nickel coating . .	1f (EKh)	1; 2; 3; 4 (P)	10-12	0.3-0.4	10-15	0.0	0.0	15; 5; 4	1	6	15	1; 2	2-3	3-12		8-10	1
Engraving by hand or printing by method of impression	5b, 5e (KIS)	1; 4; 7 (PP)	30-50	-	-	-	-	1; 2; 6; 7; 8	2	6	2; 8; 18	37	-	-	5-20	2-4	11
Engraving by etching	1i (EKh)	6; 7; 5 (PP)	2-10	0.01-0.1	-	0.0	0.0	4; 5; 7	1	6	1	37	2-3	10-100	-	3-6	3
Hollowing of cavities and openings of blind and through shapes (manufacture of dies, press molds and so forth) . . .	2e (AM)	1; 7 (PP)	19-25	5-15	2-3	15-50 passes per sec	-	1	2	6	2; 3; 8; 18	19	2-4	-	50-250	4-6	13
	5e (KIS)	1; 2; 12 (P)	70-160	-	14-70	-	50-200	1; 2; 6; 7	2	6	1; 18	7; 8; 14	2-4	-	70-300	4-6	10; 11
	5f (KIM)	9 (P)	20-30	-	-	-	0.5-12	1; 6; 7; 8; 9	2	6	1	7; 8; 14	2-5	-	5000-6000	3-4	10
	1g (EKh)	1; 7; 9 (PP)	15-30	100-150	-	0.0	0.0	1; 2	2; 7	6	1; 18	17	2-4	2000-3000		3-5	3
Finishing tool, rollers, shafts, dies, etc	2h, 2i, 2j (AM)	1; 4; 5; 7 (P)	Steel 10-20	0.5-1	3-6	0.5-1.0	0-1	1; 3; 6	3; 15	1; 2; 3; 4; 9	2; 8; 18	38	1-2	-	5-15	8-20	4; 13
		10	Hard alloy 10-15	1-2	10-15	0.5-1.0	0-1	1; 3; 6	3; 15	1; 2; 3; 4; 9	18	38	1-2	-	5-10	5-10	4; 13
	(EKhM)	4; 7; 5 (PP)	6-10	-	-	1-2	0.0	1; 3	3	1; 2; 3; 4; 9	2; 8; 18	38; 50	1-2	-	5-10	10-12	3
Finishing of gauges	1f (EKh)	1; 3; 5; 6 (O)	5-12	0.1-0.5	10-25	0.0	0.0	4; 5; 7	1	6	1	1; 2	-	-	2-5	9-11	1
	6b (KhM)	1; 4; 6; 7 (P)	-	-	-			1; 6; 7	3	1; 2; 3	18	50	1-2	-	2-10	8-11	2
Sharpening of blades of surgical cutting instruments, producing conicity of points, manufacture of needles etc . . .	1c, 1d (EKh)	3; 4; 5; 7 (P)	5-12	0.1-0.4	10-25	0.0	0.0	-	1	1	2	1; 2; 5	2-3	1-5		5-9	1; 3
Rough sharpening of cutting tools	3e (EK)	6; 7 (PP)	10-11	50-60	5-6	30-40	100-200	1; 3	3	9	5; 8	32	On machine	400-500	-	2-3	9; 10; 14

*P – industrially mastered; PP – semi-industrially mastered; O – experimental method.

Table 1 (continued)

Operation	No. figure in text (conditional designation of method)	Effectiveness of operation according to Table 7 (degree of mastering)	Operating voltage in v	Density of current in a/cm²	Specific power consumption kw'hr/kg	Speed of tool movement in m/sec	Wear of tool in %	Material of tool (in Table 5)	Shape of tool (per Table 4)	Shape of parts (per Table 3)	Basic processed materials (per Table 2)	Equipment (per Table 6)	Precision per GOST, class	Speed removal of metal in mm/min	Speed removal of metal in mm³/min	Purity of treated surface, class per GOST 2789-59	Composition of medium (per Table 8)
Rough sharpening of cutting tools	2d (AM) 5j	4; 7 (P) 7 (PP)	18-22 20-40	15-25 10-20	3-5	12-20 1-2	15-20 100-200	1; 3; 6 1; 2; 6	3 3	9 9	5; 8; 18 5; 8; 18	32 32	The same "	1000-5000	120-200 8	4-6 9	13 10; 14
Finish sharpening of cutting tools . . .	2d (AM)	4; 7 (P)	10-15	1-4	10-15	12-20	2-5	1; 3; 6	3	9	5; 8; 18	32	On machine	30-100	1-20	6-8	4; 13; 14
	3e (EK) 6c (EM)	6; 7 (PP) 1; 4; 6; 7 (P)	1.5-1.8 -	5-6 -	4-5 -	30-40 -	150-300 -	1; 3 1	3 3	9 6	18 18	32 50	" " 1-2	20-40 -	 2-10	7-8 8-11	3; 10; 14 2
Surface or through hardening	4b, c, d, e (NE)	1; 3; 5; 9 (P)	250-300	4-6	-	0.0	0.0	3	1		1	4; 5; 6	Without change	-	-	Without change	5; [illegible]
Manufacture of chip grooves on cutters .	5o, 6p (EIS)	1; 3; 5; 7; 11 (P)	20-60	-	14-70	-	-	1; 2	2.4	9	18	35	2-3	-	-	-	10; 14
Extraction of broken tool and mount	5h (EIS) 3j (EK)	1; 8 (P) 1; 8 (P)	20-100 15-25	- -	14-70 -	- -	- -	1; 2; 7 1; 2	4; 6 4; 6	6 6	1 1	31; 7; 8 31; 41	2-4 3-4	- -	60-200 400	- -	8; 10; 14 9
Branding or marking	1k, i (EK) 5b, e, k (EIS)	5; 6; 7 (PP) 1; 4; 7 (PP)	2-10 30-50	0.01-0.1 -	- -	0.0 -	0.0 -	4; 5; 7 1; 2; 6; 7; 8	1 2	6 6	1 2; 8; 18	36 37	- -	10-100 -	- 5-20	3-6 2-4	1; 3 10
Heating for pressure heat treatment and for other purposes . . .	4f (NE)	1; 3; 5; 9 (P)	250	4-6	-	0.0	0.0	8	1	6	1	4; 5; 6	Without change	-	-	Without change	5; 6
Cutting of slots and grooves	5c, e, f (EIS)	9 (0)	70-160	-	14-70	-	-	1; 2; 6; 7	2; 7	6	1; 18	7; 8	2-4	-	20-100	3-5	10; 11; 14
	5c, e, f (EIM)	9 (0)	20-30	-	-	-	-	1; 2; 6; 7	2; 7	6	1; 18	7; 8; 12	2-4	-	2000-3000	2-4	10
Broaching holes with curvilinear axis . .	5t (EIS)	9 (PP)	70-160	-	14-70	-	-	1; 2; 8	2	6	1; 18	7; 8	2-4	-	10-150	4-6	10; 11; 14
Cutting of blanks and semiproducts . .	6d (EM) 2b, c (AM)	3; 4; 7 (PP) 1; 7; 9; 11 (P)	- 20-28	- 70-500	- 3-5	- 15-20	- -	1; 3 1; 2; 3	14 14; 8	4 6	18 1; 18	22; 23 21; 22	2-3 3-4	- 8-25 cm²/min	20-50 2000-6000	5-7 2-4	2 12; 13; 14
	3b (EK)	1; 2; 5 (P)	7-10	1000-1500	1-2	25-50	0.0	1; 3	14; 8	6	1; 18	21; 22; 23	3-5	-	1000-2000	1-2	8; 9; 10; 12; 14
	5c, d (EIS)	5; 7; 9 (P)	60-150	-	-	15-25	-	1; 2; 3	14; 8	6	1; 18	13; 21; 22; 23; 24	3-4	6-18 cm²/min		2-3	10; 14; 14
Boring holes . . .	1g (EK) 1e (AM)	1; 7; 9 (PP) 1; 7 (PP)	15-30 19-25	100-150 5-15	- 2-3	0.0 15-50 passes per sec	0.0 -	1; 2 1	2; 7 2	6 6	1; 18 2; 3; 8; 19	17 19	2-4 2-4	500-1500 50-250	200-300 -	3-5 4-5	3 13; 14
	3j (EK) 5e, f (EIS)	1; 7; 9 (P) 1; 7; 9 (P)	20-30 70-160	500-1000 -	- 14-70	- -	- -	1; 2 1; 2; 6; 7	2; 7 2; 4	6 6	1; 18 1; 18	55 7; 8; 10; 11	3-4 2-3	- -	- 20-600	1-3 5-7	1-3 10; 11
Boring of small holes	5g (EIS)	1; 3; 5; 7 (P)	70-160	-	14-70	-	-	1; 2; 6; 7	2; 4	6	1; 18	7; 8; 33; 34	2-3	-	20-600	5-7	10
	5j (EIS)	1; 7; 9 (PP)	70-160	-	-	-	-	1; 2	2	7	1	7; 8; 33; 34	2-4	-	20-200	4-6	10; 11
	5g, j (EIM)	1; 7; 9 (PP)	20-30	-	-	-	-	1; 2	2	7	1	7; 8	2-4	-	100-600	3-5	10
	1k (EK)	1; 7; 9 (PP)	4-10	0.1-0.5	-	0.0	0.0	4; 5; 7	2	6	1	1; 2	2-3	-	50-200	4-7	3

Table 1 (Continued)

Operation	No. figure in text (conditional designation of method)	Effectiveness of operation according to Table 7 (degree of mastering)	Operating voltage in v	Density of current in a/cm^2	Specific power consumption kw-hr/kg	Speed of tool movement in m/sec	Wear of tool in %	Material of tool (in Table 5)	Shape of tool (per Table 4)	Shape of parts (per Table 3)	Basic processed materials (per Table 2)	Equipment (per Table 6)	Precision per GOST, class	Speed removal of metal: in $\frac{\mu}{min}$	Speed removal of metal: in $\frac{mm^3}{min}$	Purity of treated surface, class per GOST 2789-59	Composition of medium (per Table 8)
Hard-facing	0.5k (EK)	9 (PP)	10-30	-	-	-	-	From coating metal	4	1; 2; 9	2	43; 44	-	-	-	1-2	9; 4; 5
Cutting threads . .	5l (EIS)	6; 9 (PP)	25-100	-	-	0.02	-	The same	4	6	2.8	20	3-4	-	-	-	9
	2k (AM)	1; 3; 5; 3 (PP)	4-20	0.5-15	3-20	-	-	2	2; 9	1	2; 8; 18	-	2-3	-	-	5-7	4; 13
	5n (EIS)	1; 3; 5; 9 (PP)	30-70	-	-	-	-	2; 2	2; 9	1	2; 8; 18	40	2-4	-	-	4-6	10
Degreasing	1b (EK)	1; 4 (P)	3-8	0.05-05	10-40	0.0	0.0	4; 5; 7	1	6	1	1.2		-	-	-	1; 3; 4; 5; 6; 13
Purification of surfaces	1b (EK)	1; 4 (P)	3-8	0.05-02	10-40	0.0	0.0	4; 5; 7	1	6	1	1.2	3-4	0.1-5	-	-	1; 3; 4; 5; 6; 13
	1e (EK)	1; 4 (PP)	6-12	-	-	0.0	0.0	3; 6	1	6	2; 3; 8	54	-		-	-	7
	3g (EK)	1; 2; 3; 5; 6; 9 (PP)	7-15	1500 and higher	0.8-2	35-40	-	3	13	1; 3; 8	2.3	49; 53	2-4	2-3 m^2/hr	10,000	2-3	9
Burnishing of spheres	3f (EK)	1; 2; 3; 5; 7 (P)	6-25	-	10	7-30	60	1; 3; 6	3	11	2	46	3-4	-	15,000	1-3	8; 9
Roughing of ingots and semiproducts . .	2f (AM)	1; 5; 7; 12 (P)	16-20	8-15	10-20	20-30	-	1; 3; 6	3	1; 2; 3; 4; 9	2; 8; 18	9; 26; 28; 29; 30	2-3	-	50-600	6-7	12; 13; 14
	3c, d (EK)	1; 2; 3; 5; 7 (PP)	10-30	-	2-3	25-50	0.0	1; 3; 6	3	5	2; 3; 8	30	4-5	-	10,000 15,000	1-2	-
Oxidizing	1a (EK)	1; 6 (P)	10-30	-	-	0.0	0.0	4; 8	1	6	9; 10; 11	1; 2	2-3	-	-	-	2-6
Piercing thin holes	5g (EIS)	1; 3; 5; 7 (P)	70-160	-	14-70	-	-	1; 2; 6; 7	2; 4	6	1; 18	7; 8	2-3	-	20-600	5-7	10; 11
	5g (EIM)	1; 3; 5; 7 (P)	20-30	-	-	-	-	1; 6; 7; 8; 9	-	-	-	-	2-4	-	5000-6000	3-4	10
Piercing holes and cavities	5e, f (EIS)	1; 3; 5; 7 (P)	70-160	-	14-70	-	-	1; 2; 6; 7	2.4	6	1; 18	7; 8	3-5	-	20-600	3-6	8;;10; 11; 14
	3j (EK)	1; 7; 9 (P)	20-30	500-1000	-	-	-	1; 2	2; 7	6	1; 18	55	3-4	-	-	1-3	8; 10; 14
	5b, e (EIM)	1; 3; 5; 7	20-30	-	-	-	-	1; 6; 7; 8; 9	-	-	-	-	2-4	-	5000-6000	3-4	10
	2b (AM)	1; 7 (PP)	19-25	5-15	2-3	15-50 passes per sec	-	1	2	6	2; 3; 8; 18	19	2-4	50-250	-	4-5	12; 13; 14
Volume profiling ..	1j (EK)	4; 6; 7 (O)	6-15	0.1-1.0	10-30	-	-	1; 2	1	6	1	39	2-3	-	10-200	6-8	-
	2k (AM)	1; 3; 4; 7; 9 (O)	16-20	8-150	10-20	2-10	-	1	9; 15	1; 2	2; 8; 18	40	1-2	-	100-200	6-8	-
	3h (EK)	1; 3; 4; 6 (PP)	0.1-2	-	-	0.25-5	-	10	12	1; 2	2; 3; 8	48	1-3	-	10,000 40,000	5-8	-
	3d (EK)	1; 9; 7 (O)	20-40	-	2-4	15-20	-	1; 3; 6	15	6	2; 18	48	2-4	-	5000-8000	1-3	9
	5n (EIS)	1; 3; 5; 9 (P)	60-150	-	-	-	-	1; 2	2; 7	6	1; 18	7; 8	2-4	-	50-100	2-5	10
	5n (EIM)	1; 3 (P)	20-30	-	-	-	-	1; 6; 7; 9	2; 15	1; 2	1; 18	40	3-5	-	1000-2000	3-5	10
Coating surfaces with metals	3k (EK)	9 (PP)	10-30	-	-	-	-	From coating metal	4	1; 4; 9	2	43	-	-	-	1-2	4; 5; 8
	5l, k, r (EIS)	9; 6 (P)	25-100	-	-	-	-	The same	4	6	2; 8	20	3-4	-	-	3-5	9
Soldering and brazing	4g (ME)	1; 4; 5; 6; 10 (P)	250-300	4-6	-	0.0	0.0	1	6	1	4; 5; 6	-	-	-	-	-	5
Polishing decorative ferrous metals and alloys	1a, f (EK)	1; 2; 3; 4 (P)	10-15	0.3-0.4	10-30	0.0	0.0	4; 5; 7; 15	1	6	2; 9; 11	1; 2; 15; 16	2-3	7-10	-	1-2 classes higher than initial	1

Table 1 (Continued)

Operation	No. figure in text (conditional designation of method)	Effectiveness of operation according to Table 7 (degree of mastering)	Operating voltage in v	Density of current in a/cm^2	Specific power consumption kw·hr/kg	Speed of tool movement in m/sec	Wear of tool in %	Material of tool (in Table 5)	Shape of tool (per Table 4)	Shape of parts (per Table 3)	Basic processed materials (per Table 2)	Equipment (per Table 6)	Precision per GOST, class	Speed removal of metal in $\frac{\mu}{min}$	Speed removal of metal in $\frac{mm^3}{min}$	Purity of treated surface, class per GOST 2789-59	Composition of medium (per Table 8)
Polishing decorative nonferrous metals and alloys	1f (EK)	1; 2; 3; 4 (P)	5-7	0.1-0.5	5-20	0.0	0.0	4; 5; 7; 15	1	6	13; 15; 16; 17; 23	1; 2; 15; 16	2-3	3-5	-	The same	1
Polishing tools . .	1c (EK)	1; 2; 3; 4 (P)	10-15	0.3-0.4	10-30	0.0	0.0	4; 5; 7; 15	1	6	2; 9; 11	1; 2	2-3	3-10	-	" "	1
Smoothing of steel surface	1h (EK)	1; 3; 6; 7; 10 (PP)	6-15	0.1-1.0	10-20	0.0	0.0	4; 5; 7	1	6	1	1; 2	2-3	-	50-500	3-6	1; 3
	2g (AM)	1; 5; 7; 12 (P)	16-20	8-15	10-20	20-30	-	1; 3; 6	3	1; 2; 3; 4; 9	2; 8; 18	9; 26; 27; 28; 29; 30	2-3	-	50-600	6-7	4; 13
	2j (AM)	1; 4; 7 (P)	14-16	3-7	15-25	20-30	-	1; 6; 7; 11	3	1; 2; 3; 4; 9	2; 8; 18	9; 26; 27; 28; 29	2-3	-	5-15	6-8	4; 13
	3i (EK)	3; 4; 5 (PP)	0.1-1	200-500 (current)	-	2-6	-	10	11	1	2; 8	42	1-2	-	-	8-10	9
Removal of projecting edges and burrs .	1f (EK)	1; 2; 3; 4 (P)	10-15	0.3-0.4	10-30	0.0	0.0	4; 5; 7; 15	1	6	2; 9; 11	1; 2	2-3	-	-	-	1; 3
Heat treatment . . .	4c, d, e (NE)	1; 3; 5; 9 (P)	250-300	4-6	-	0.0	0.0	3	1	6	1	4; 5; 6	Without change	-	-	Without change	5; [illegible]
Sharpening	2k (AM)	1; 3; 4; 7; 9 (P)	16-20	8-150	10-20	2-10	-	1	9; 15	1; 2	2; 8; 18	40	1-2	-	100-200	6-8	4; 13
	3h (EK)	1; 3; 4; 6 (PP)	0.1-2.0	800-1000 (current)	-	0.25-5	-	10	12	1; 2	2; 3; 8	47; 48	1-3	-	10,000-8000	5-8	-
Etching	1b (EK)	1; 4 (P)	3-8	0.05-0.2	10-40	0.0	0.0	4; 5; 7	1	6	1	1; 2; 56	3-4	-	-	-	3
Super finishing . .	1h (EK)	1; 3; 6; 7; 10 (PP)	6-15	0.1-1.0	10-20	0.0	0.0	4; 5; 7	1	6	1	1; 2	2-8	-	50-500	3-6	
	6b (XM)	1; 4; 6; 7 (P)	-	-	-	-	-	1	3	1; 2; 3; 4; 9	18	50	1-2	-	2-10	3-11	2
	2j (AM)	1; 3; 4; 5 (P)	4-5	0.5-1.2	3-6	0.5-1.0	-	1; 3; 6	2.3	1; 2; 3; 4; 9	2; 8; 18	25; 26; 27; 28; 29; 38	1-2	-	5-15	10-12	4
Rough grinding . . .	6b (XM)	1; 4; 6; 7 (P)	-	-	-	-	-	1	3	1; 2; 3; 4; 9	18	50	1-2	-	2-10	3-11	2
Finish grinding . .	2i (AM)	1; 4; 7 (PP)	10-20	0.5-1.0	8-15	30	-	1; 6; 11; 12	5	1; 4	2; 8; 18	18	1-2	-	2-20	9-11	4
	6b (XM)	1; 4; 6; 7 (P)	-	-	-	-	-	1	3	1; 2; 3; 4; 9	18	50	1-2	-	2-10	8-11	2
	2g, h (AM)	1; 4; 7 (P)	14-16	3-7	15-25	20-30	-	1; 6; 7; 11	3	1; 2; 3; 4; 9	2; 8; 18	9; 25; 26; 27; 28; 29	1-2	-	5-50	8-10	4; 13
	5q (EIS)	7; 9 (PP)	20-60	-	-	-	-	1; 3; 6; 7	3	1; 2; 3; 4; 9	2; 8; 18	9; 26; 27; 28; 29	2-3	-	5-15	6-8	10; 14
Finish grinding . .	2f (AM)	1; 5; 7; 12 (P)	16-20	8-15	10-20	20-30	-	1; 3; 6	3	1; 2; 3; 4; 9	2; 8; 18	9; 26; 27; 28; 29; 30	2-3	-	50-60	6-7	13
	3d (EK)	1; 5; 7; 10 (PP)	1.5-10	5-50	4-6	30-40	-	1; 3	3	1; 2; 3; 4; 9	2; 8	9; 26; 27; 28; 29; 30	2-4	-	100-1500	2-4	8; 9; 12; 14
	5q (EIS)	1; 7 (P)	30-100	-	14-16	-	-	1; 2; 6	3	1; 2; 3; 4; 9	2; 8; 18	9; 26; 27; 28; 29; 30	2-4	-	20-500	4-5	8; 10
Hardening tools . .	6i (EIS)	9; 6 (P)	25-100	-	-	0.02	-	From coating metal	4	6	2; 8	20	3-4	-	-	3-5	9
Removal of scale . .	1b (EK)	1; 2; 4 (P)	3-8	0.05-0.2	10-40	0.0	0.0	4; 5; 7	1	6	1	1; 2	3-4	-	-	-	1; 3
	1e (EK)	1; 4; (PP)	6-12	-	-	0.0	0.0	3; 6	1	6	2; 3; 8	54	-	-	-	-	7
	5g (EK)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	9

Table 2. Processed Materials (groups)

No.	Designation of material	No.	Designation of material
0	Any metallic and nonmetallic materials	12	Silumin
1	Any metals and metal alloys	13	Pure copper
2	Ferrous metals and alloys (except cast iron and high-speed steels)	14	Low-copper alloys, including two-phase brasses and bronze
3	Cast iron	15	High-copper alloys, including single-phase brasses
4	Low- and medium-carbon, constructional and building	16	Pure nickel and coatings
5	Steels, high-carbon tool steels	17	High-nickel alloys
6	Low- and medium-carbon structural	18	Powder metal alloys
7	Steels, high-alloy special steels	19	Cermets
8	High-speed tool steels	20	Semiconductor materials (germanium, silicon)
9	Pure aluminum	21	Brittle nonmetals (glass porcelain, ceramics)
10	Pure magnesium	22	Any plastic materials
11	Aluminum and magnesium alloys (besides silumin)	23	Precious metals and alloys
		24	Oxides, nitrides, carbides — high refracturability
		25	Special metals and alloys

Table 3. Types of Processed Articles

No.	Shape of articles or parts	Examples
1	Solids of revolution of simple forms	Dies, rollers, gauges, round shafts, rods, cases, pins, pulleys, washers, pistons, spindles, mounts, flanges
2	Solid of revolution of complex form	Cams, crankshafts, milling cutter, pinions, cylindrical springs, eccentric gears
3	Flat complicated form	Connecting rods, forks, nut wrench, shaped nuts, gear rods
4	Flat simple forms	Flat gauges. Flat springs, plate, sheet, plate, tools, holder of cutters. Sponges of clamp attachmetns, stamps
5	Shaped complicated configuration	Fittings, angle fittings of press-forms, stamps, attachment, housings
6	Any forms	Parts and articles of any assignment with any asymmetry of parts

Table 3 (Continued)

No.	Shape of articles or parts	Examples
7	Thin-plates	Sheet metal of snail thicknesses
8	Metallurgical ingots	Round, square, polyhedral, metal ingots
9	Special	Metal-cutting and woodworking tools, with plates of hard alloys
10	Special	Stamps and press holds for pressing, die casting
11	Special	Balls for bearings

Table 4. Forms of Current-Conducting or Processing Electrodes

No.	Form	No.	Form
1	Cathode plates	8	Metallic or wire strip
2	Negative electrode-tool with respect to article	9	Flat pattern on section of article
3	Smooth disk or with massive grooves	10	Cathode shaped plates
4	Wire or rod	11	Shaped cutters of lathe type
5	Abrasive bar (hone)	12	Ordinary lathe cutter
6	Hollow (tubular) electrode-tool	13	Wire brush
7	Electrode-tool — plate	14	Thin metal disk
		15	Axles, rollers, feelers

Table 5. Materials of Current-Conducting or Processing Electrodes

No.	Material	No.	Material
1	Cuprite	9	[Pyrolitic] graphite
2	Copper alloys, in particular brass	10	Powder metal hard alloy
3	Carbon steel	11	Abrasive metals
4	Acid-resistant alloy steel	12	Abrasives
5	Lead	13	Tree
6	Cast iron	14	Rubber, plastic
7	Graphite	15	Nickel
8	Aluminum and its alloys		

Table 6. Equipment*

No.	Designation	No.	Designation
1	Bath, standard galvanic type with rods, preheating, circulation of electrolyte, lining	21	Universal disk cutting machine
2	Bath, special galvanic type for definite operation of all equipment	22	Universal ribbon cutting machine
3	Bath for etching, lined, without feed of current	23	Special disk cutting machine
4	Universal installation for electrolyte heating with bath, equipment and mechanisms of control	24	Special ribbon cutting machine
5	Sp cialized semiautomatic installation for electrolyte heating	25	Profile polishing machine
6	Installation for electrolyte heating — automatic machine	26	Universal circular grinding machine
7	Universal printing — piercing machine	27	Special circular grinding machine
8	Special piercing machine	28	Universal internal grinding machine
9	Universal polishing machine	29	Special internal grinding machine
10	Boring machine, universal	30	Stripping-polishing machine
11	Boring machine, special	31	Installation for removal of fragments of tool and mount
12	Machine for cutting narrow slots	32	Sharpening machine for tools
13	Machine for cutting pipe	33	Operation machine for small holes
14	Machine for cutting holes in pipes	34	Machine for drilling small holes
15	Installation for continuous electropolishing of strip and wire	35	Machine for manufacture of chipping grooves
16	Installation for electro-polishing pipe	36	Installation for branding and marking
17	Installation for electro-chemical drilling and piercing	37	Machine for engraving and branding
18	Boring-grinding machine	38	Finishing machine
19	Mortising machine for manufacture of cavities	39	Installation for electro-chemical profiling
20	Installation for hardening of tools and applying of thin coverings	40	Machine for volume profiling of solids of revolution on flat plate
		41	Installation for electric-contact drilling of holes

*Only types of equipment are enumerated. Concrete models and grades are defined depending upon conditions.

Table 6 (Continued)

No.	Designation	No.	Designation
42	Machine for electric-contact smoothing of solids of revolution	49	Installation with electric-contact revolving brush
43	Installation for vibration-contact hard-facing	50	Installation with disk or block and bath for electro-chemical-mechanical grinding or polishing
44	Installation for electric-contact welding of sheet and wires	51	Automatic or semiautomatic installation for electro-chemical sharpening
45	Installation for applying of superhard alloys by plasma arc	52	Galvanic bath with feed of ultrasonic pulses
46	Machine for electro-contact rolling of spheres	53	Machine for electric-contact purification with metal wheels
47	Machine for electric-contact sharpening of solids of revolution	54	Metal bath with heating and feed of current for treatment in fused salts
48	Machine for electric-contact treatment of profiled articles	55	Installation for electric-contact drilling (broaching)

Table 7. Indicators of Effectiveness of Treatment*

No.	Index of effectiveness as compared to usual (mechanical) methods	No.	Index of effectiveness as compared to usual (mechanical) methods
1	Lowering labor of treatment	8	Decreasing rejects
2	Removal of physical labor	9	Possibility of fulfillment of operation, impracticable by ordinary methods
3	Increasing productivity		
4	Improvement of quality	10	Significant acceleration of operation (intensification)
5	Possibility of mechanization of operation	11	Economy of materials
6	Simplification of technological process	12	Reduction of number of changes during treatment
7	Economy of abrasives and tools		

*Quality characteristic of effectiveness is noted. Quantitative values can be different.

Table 8. Basic Technological Media, in Which Electrical or Chemical-Mechanical Treatment is Called Out

No.	Composition of medium*	No.	Composition of medium*
1	Concentrated acids and their mixtures (phosphoric, chromic, sulfuric, etc.)	6	Weak solutions of alkalis (N_2OH, KOH and so forth)
2	Mixture of agneous solutions of salts of heavy metals (for instance, sulfates of copper, silver and others) with abrasive powder (for instance, carborundum)	7	Melts of anhydrous alkalis (N_2OH, KOH and so forth)
		8	Technical water
		9	Air
		10	Mineral oil
3	Agneous solutions of chloride salts (for instance, chlorides of potassium, sodium)	11	Kerosene
		12	Agneous suspension of colloidal silicates (clay, bentonite, and so forth)
4	Agneous solutions of borates and phosphates	13	Agneous solutions of silicates of sodium or potassium (soluble liquid glass)
5	Agneous solutions of carbonate salts (for instance, carbonates of sodium, potassium)	14	Oil-water emulsion
		15	Agneous solutions of acids or alkalis of different concentration

*Exact prescriptions and concentration in each particular case is indicated in corresponding technological aids or instructions.

In connection with the novelty of electrical methods being established, a conventional classification of them does not yet exist.

Among the large variety of presently known methods of electrical treatment of materials the following are basic:

1. Electrochemical [EKh] — carried out for the most part with direct current of low voltage in medium of current-conducting liquids (electrolytes). The metal is corroded and removed as a result of electrochemical processes.

During flow of constant electrical current between electrodes 3 and 4 (Fig. 1a), immersed in electrolyte b, anode dissolution

occurs, i.e., transition of metal into solution from the anode surface (electrode 3, connected with the positive pole of the current source.

Anode dissolution is used in operations of electrochemical purification of a metal surface, electropolishing, grinding and finishing, removal of projecting edges and burrs, sharpening cutting tools and several other operations.

Simultaneously with anode dissolution, at the cathode (electrode 4, connected with the negative pole of the current source) there occurs a process of separation of metal that can be used basically in galvanic plastics and electroplating. These phenomena are the basis of operation of cathode removal of scale and electrocementation.

The characteristics of certain operations of electrochemical treatments are given below.

Purification of metal surfaces, by anode etching, from oxides, rust, grease films and other similar contaminations (Fig. 1b) consists of removal from the surface of part 3, together with the dissolved metal of the contaminants (oxides, rust, grease films). A purified surface usually is rough. The electrolyte is a solution of acids or salts. The operation is applicable to different metals and alloys.

Electrochemical honing of a cutting tool and sharpening is carried out by means of creating an increased current density on the processed surfaces at the expense of their corresponding orientation relative to the cathode (Fig. 1c).

The nature of sharpening depends on the initial angle of sharpening and position of part relative to the cathodes. Electrolyte 2 – solutions of acids.

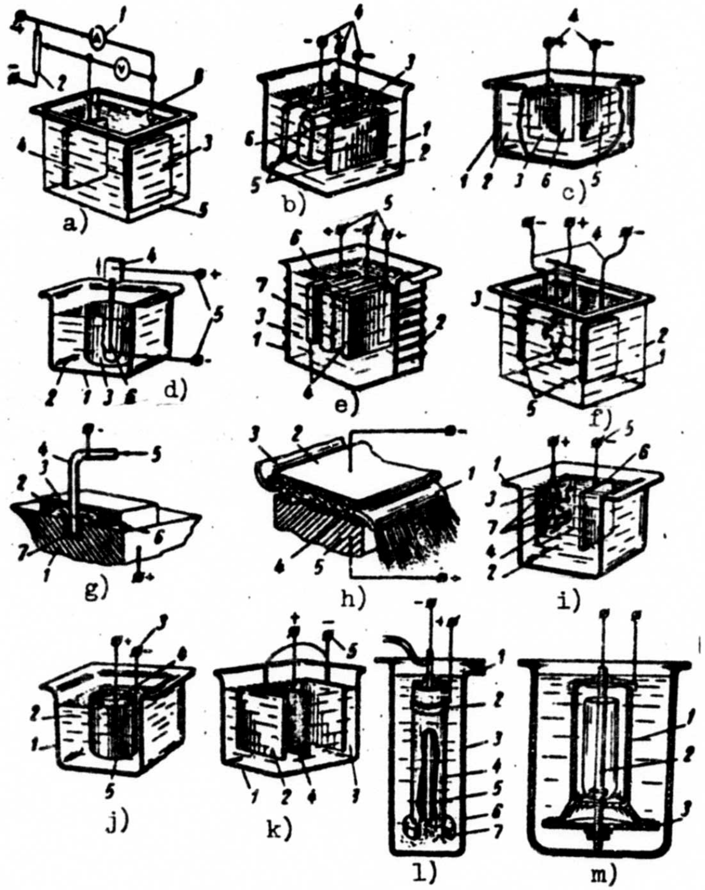

Fig. 1. Electrochemical treating methods: a) fundamental diagram: 1 – ammeter; 2 – voltage divider (power source); 3 – anode; 4 – cathode; 5 – bath; 6 – electrolyte; b) purification of metal surfaces from contaminations by anode etching: 1 – bath; 2 – electrolyte; 3 – cleaned part – anode; 4 – power source; 5 – cathodes; 6 – removed layer of contaminations; c) sharpening and honing a cutting tool: 1 – bath; 2 – electrolyte; 3 – honed tool – anode; 4 – power source; 5 – cathode; 6 – tool blade; d) manufacture of conical parts, pins, etc.: 1 – bath; 2 – electrolyte; 3 – cathode; 4 – mechanism of uniform rise of part; 5 – current source; 6 – sharpened part; e) cathode removal of scale from the surface of steel parts: 1 – steel bath; 2 – heater; 3 – electrolyte – molten salt; 4 – anodes; 5 – current source; 6 – cleaned part; 7 – removed (reduced) film of scale; f) glazing and polishing of metal surfaces: 1 – electrolyte; 2 – bath; 3 – treated part – anode; 4 – current source; 5 – cathodes; g) cutting holes and recesses in metals: 1 – part – anode; 2 – housing of local bath; 3 – bath recess; 4 – tube – cathode (tool); 5 – supply of electrolyte from pump; 6 – electrolyte discharge; 7 – waste obtained during dissolution of hole; h) smoothing rough surfaces: 1 – electrolyte discharge; 2 – cathode plate; 3 – discharge of electrolyte in gap between electrodes; 4 – smoothed surface of part; 5 – part; i) engraving and marking on metals: 1 – bath; 2 – electrolyte; 3 – layer of varnish or wax on surface of part; 4 – engraved part – anode; 5 – current source; 6 – cathode plate; 7 – sections of anode free of varnish, dissolved to form recessed areas; j) shaping metal blanks: 1 – bath; 2 – electrolyte; 3 – current source; 4 – shaped article – anode; 5 – shaping cathode; k) manufacture of grids: 1 – bath; 2 – cathode; 3 – electrolyte; 4 – part – anode with grid printed by varnish; 5 – supply source; l) polishing short tubing: 1 – discharge of electrolyte; 2 – current feed to pipe; 3 – bath; 4 – pipe – anode; 5 – cathode; 6 – bath lining; 7 – support ring; m) polishing of shaped parts (fittings): 1 – polished part (anode); 2 – cathode; 3 – insulating inserts.

Cathode removal of scale from the surface of steel parts in molten salts (Fig. 1e) occurs as a result of reduction of iron oxides (scale) by metallic sodium, which is liberated at the cathode during electrolysis. The electrolyte is a molten caustic soda. This operation is applicable to ferrous metals and alloys. Dimensions of a part are not usually changed.

Electrochemical burnishing and polishing of metallic surfaces (Fig. 1f). During anode dissolution of a metal in the corresponding electrolyte 1 on the surface of polished part 3, a viscous film of salts will be formed, protecting microcavities from the action of current but not preventing dissolution of burns, as a result of which the surface is smoothed – polished. The best surface quality is attained during electropolishing of pure and homogeneous metals and alloys.

Electrochemical drilling of holes and recesses in metals (Fig. 1g). This is carried out in local electrolytic bath, formed by the end cathode tube 4 and part surface 1. A high current density and high speed of electrolyte flow sharply intensify dissolution. The shape and size of the drilled hole are determined by shape and size of cathode tube. The electrolyte is a solution of chloride salts.

Electrochemical polishing and finishing of rough metallic surfaces (Fig. 1h). A stream of electrolyte 3 flowing at a high velocity in the gap between cathode 2 and surface of part 4, during transmission of current of high density intensely dissolves protuberances, thereby smoothing the surface. The electrolyte is a solution of chloride salts. Uniformity of metal removal is determined by uniformity of gap.

Electrochemical engraving and marking of metals (Fig. 1i) consists of anode dissolving of part surface 4 at sections 7 where insulation is absent (varnish, wax, etc.) and the metal is exposed. As a result a deepened figure is reproduced. The electrolyte – salt solutions.

Electrochemical shaping of metal blanks (Fig. 1j). Anode dissolution of shaped part 4, placed inside cathode 5, occurs more intensely in sections closer to the cathode (in this case the corners of a square), with the result that the initial shape is changed (in this case rounding off of a square). Electrolyte – solutions of acids and salts.

Electrocarburizing of steel parts. In the process of electrolysis of melted carbonate salts (usually $BaCO_3$) carbon diffuses into the surface layer of the steel part cathode, thereby carrying out carburizing. The rate of electrocarburizing is higher than gas or liquid carburizing.

Electrochemical manufacture of grids (Fig. 1k) is analogous to electrochemical engraving. On the anode surface grid 4 is applied, protecting the metal under it from dissolving; whereas exposed areas are dissolved. This operation is used for obtaining grids in thin sheets. Electrolyte – solutions of acids and salts.

Electrochemical manufacture of sheet metal of small thicknesses. By controlling time and current the process of anode dissolving of sheet metal, reduces thickness of the latter to several microns. Electrolyte – solutions of acids. The operation is applicable to pure and uniform metals.

2. Anode mechanical [AM] or electrochemical-mechanical [EKhM] – conducted under conditions similar to the preceding, but with a

simultaneous mechanical effect on the processed surface.

Two basic varieties of anode machining are known clean — yield of metal occurs as a result of the combination of electrochemical action of current and mechanical action, and rough — at which, along with mechanical action electrothermal phenomena starts to play a significant role — liberation of heat at points of electrode contact. During the clean treatment mechanical removal of dissolution products can be produced by any electrically neutral tool, and also by rapid flow of electrolyte or moving cathode. During rough treatment the necessary mechanical action is produced only by the moving cathode.

The fundamental diagram of anode machining is shown in Fig. 2. During passage of direct current through electrolyte 3 and electrodes 1 and 4 dissolution of the anode surface occurs with formation of films which are removed by mechanical means (moving metal cathode or electrically neutral tool).

The necessary treatment is carried out by direct removal of films on the corresponding sections of the part.

The anode machining method is used for cutting, roughing, adding, sharpening, polishing, clean finishing and several other operations in treating hard alloys, hardened steel and similar materials.

Characteristics of certain operations are given below.

Anode cutting (Fig. 2b and c) is produced with the help of a moving metal cathode (disk belt) which is in contact (under small pressure) through a film of the working medium with the surface of the metal being cut. Directed cutting of metal is carried out by the joint electrochemical and mechanical action.

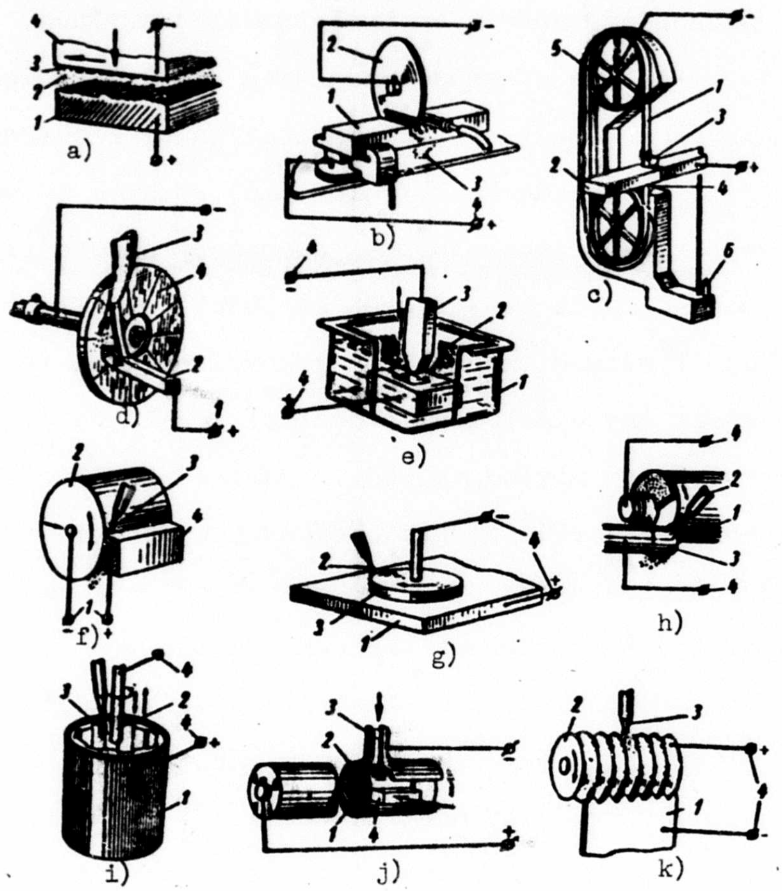

Fig. 2. Anode machining methods: a) fundamental diagram: 1 – part (blank) – anode; 2 – film of anode dissolution products; 3 – electrolyte; 4 – moving cathode; b) disk cutting: 1 – part (blank) – anode; 2 – disk – cathode; 3 – electrolyte supply; 4 – current feed; c) belt cutting: 1 – belt (cathode); 2 – blank (anode); 3 – top guide head with supply of electrolyte; 4 – bottom guide head; 5 – contact wheel with brushes for current feed; 6 – pump with tank for electrolyte; d) sharpening tool: 1 – current feed; 2 – sharpened cutter (anode); 3 – electrolyte supply; 4 – sharpening disk (cathode); e) build up: 1 – bath; 2 – electrolyte; 3 – tool-cathode; 4 – current feed; f) roughing (rough grinding): 1 – current feed; 2 – tool-cathode; 3 – electrolyte supply; 4 – part-anode; g) flat grinding: 1 – part; 2 – electrolyte supply; 3 – polished cylinder-cathode; 4 – current feed; h) round polishing: 1 – metallic disk – cathode; 2 – electrolyte supply; 3 – polished part – anode; 4 – current feed; i) lap polishing: 1 – treated part – anode; 2 – lap bars – cathode; 3 – electrolyte; 4 – current feed; j) finishing: 1 – ground part – anode; 2 – gap between electrodes, filled by electrolyte; 3 – cathode plate; 4 – abrasive scraper (tool); k) shaping (sharpening): 1 – flat tenplate-cathode; 2 – shaped part-anode; 3 – electrolyte supply; 4 – current feed.

Anode sharpening of a tool (Fig. 2d) — removal of metal or alloy from the sharpened edge 2 is carried out by electrochemical action of current flowing in the gap between cutter 2 and the rotating metal disk 4, in presence of a working fluid.

Anode finishing (Fig. 2j) consists in mechanical removal of anode products by an electrically neutral tool 4 which form on the surface of the anode-part 1 during passage of current between its surface and cathode plate 3 through electrolyte 2.

Anode polishing (Fig. 2f, g, h) is produced with the help of a rotating metal cathode, which removes the film on the part as a result of anode dissolution of its surface.

Anode grinding (Fig. 2i) is produced like mechanical honing, but with imposition of current on the system head — part. Grinding bars 2 remove a thin film from the surface of part 1, which formed as a result of electrochemical processes.

Anode shaping (Fig. 2k) is produced with the help of a tool (pattern) 1, having a cross section same as part 2, during rotation of the latter.

3. Electric-contact [EC] or electromechanical [EM] methods are based on breakdown of metal due to electrothermal processes, combined with mechanical removal of products being formed.

Contact under small pressure of two metallic electrodes (Fig. 3) "tool" 1 and "part" 2 leads to increased resistance at the point of contact. Electric current passing through the place of contact, heats, softens and can even melt the metal, facilitating its removal from the part. For preventing fusion of "tool" it moves at a high speed or is artificially cooled.

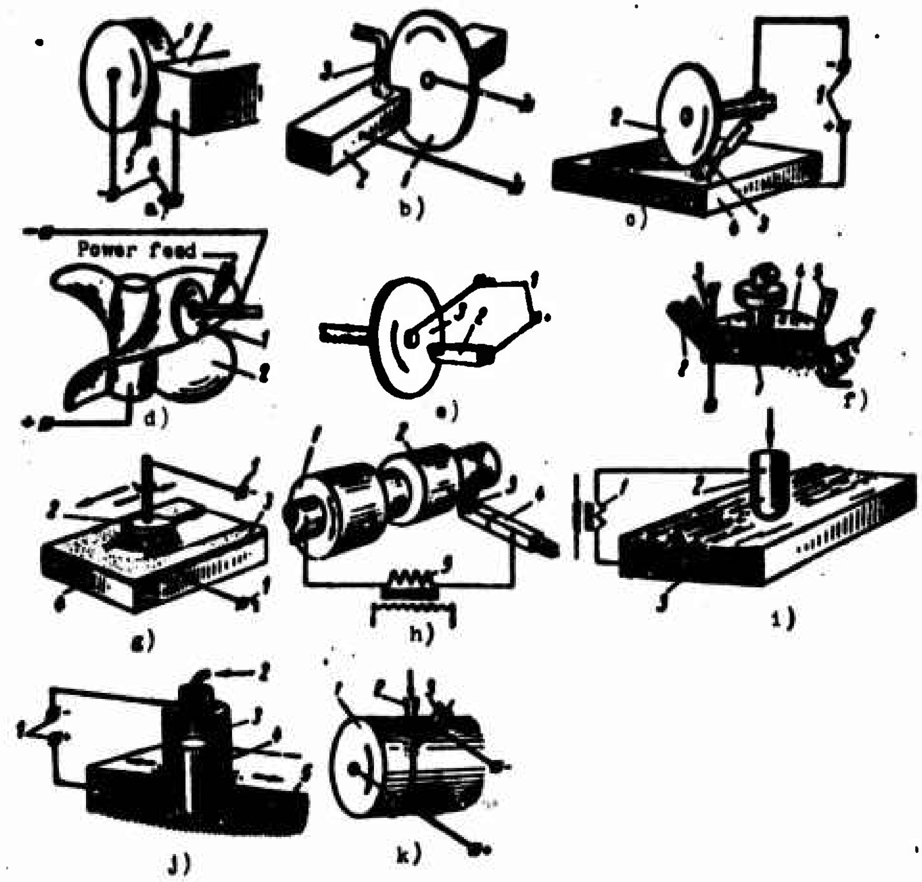

Fig. 3. Electric-contact methods of treatment. a) fundamental diagram: 1 – electrode-tool (disk); 2 – blank; 3 – zone of contact heating and melting; 4 – current feed; b) cutting: 1 – cutting disk; 2 – blank; 3 – liquid supply; c) roughing (grinding) flat surfaces: 1 – current feed; 2 – grinding disk; 3 – supply of liquid; 4 – processed part; d) roughing (grinding) shaped parts: 1 – grinding disk; 2 – surface of part; e) sharpening tools: 1 – current feed; 2 – sharpening cutter; 3 – sharpening wheel; f) polishing balls: 1 – bottom disk-electrode; 2 – groove for supply of balls; 3 – polished balls; 4 – top disk-electrode; 5 – water supply; 6 – ball exit; g) scale cleaning: 1 – current feed; 2 – wire brush-electrode; 3 – layer of scale on part; 4 – part; h) sharpening: 1 – clamping chuck; 2 – turned surface; 3 – cutter; 4 – cutter holder water-cooled; 5 – step-down transformer; i) smoothing: 1 – step-down transformer; 2 – smoothing electrode (cutter); 3 – smoothed blank; j) drilling (reaming): 1 – current feed; 2 – oil or water supply; 3 – cutting tube-electrode; 4 – cut part of blank; 5 – part; k) vibration-contact hard facing: 1 – part; 2 – liquid supply; 3 – supply of hard-facing wire.

The described phenomenon of electric-contact heat emission is used both for carrying out of operations of treatment by removal of metal (cutting, polishing, sharpening, milling, drilling, etc.), and for operations in which the metal is planned or applied (vibration hard facing, electric-contact welding).

Electric-contact sharpening of a tool (Fig. 3e). Heat, liberated during passage of an electric current through immediate resistance, created at the point of contact of the surface of the rotating disk 3 and the sharpening cutter 2, destroys the surface of the cutter in a direction assigned by the disk.

Electromechanical purification steel from scale (Fig. 3g). During contact of steel brush 2 with the surface of steel sheet 4, covered by scale 3, and transmission of current through the formed chain heat is liberated at the point of contact, melting the scale which is removed by a rotating brush.

High-speed electroerosion (Fig. 3d). Contact of a metallic disk-tool 1 with the metal surface of part 2 in the presence of water, during passage of an electric current of high density, leads to intense erosion of the part. Direction of erosion is determined by movement of disc.

Deep electric-contact drilling (Fig. 3j); metal is eroded with the help of a metallic tube-tool 3, in contact with part 5 in presence of liquid 2 and during passage of an electric current. Eroded metal is removed by a stream of liquid.

Vibration-contact hard facing (Fig. 3k). A strong layer of metal is applied on blank 1 by melting electrode wire 3 during contact with blank. Rotation and logitudinal vibration of wire 3, and also presence of liquid 2 prevent strong heating of blank 1, the

properties of which remain unchanged.

Electromechanical sharpening (Fig. 3h). Application of an electric current of low voltage and high density to cutting system – part leads to intense liberation of heat in their zone of contact 3 which changes the conditions of cutting, increasing productivity or purity of treated surface.

Electromechanical smoothing (Fig. 3i). Smoothing of burrs from rough surface 3 is produced with help of roller or cutter 2, traveling under pressure along the smoothed surface during passage of an electric current of low voltage and high density between them liberating heat and softening contact sites.

4. Methods of heating metals in electrolytes [HE]. Here they use intense heat liberation in a thin vapor film, forming on the surface of the cathode during electrolysis by high voltage and high density current.

Heating in an electrolyte is used for a number of operations of heat treatment in mass production. This method allows to carry out local or over all heating of any metallic current-conducting materials and parts with great speed, without oxidation of surfaces to any noticeable depth.

Essence of this method consists in the following (Fig. 4a). During passage of direct current of the corresponding voltage and density through electrolyte 2 between electrodes 1 and 4, the surface of cathode 4 is rapidly heated to a high temperature. Heating is caused by spark discharges between the surface of cathode 4 and electrolyte 2, creating a pulsing heat flow, and also exothermic reactions in gaseous "shell" 5, formed around the cathode. The process usually occurs in two phases, the first of which –

intermittent discharge at the correct regime — is brief or absent, while the second phase — discharge through the stable gas shell — is the leading factor of heating.

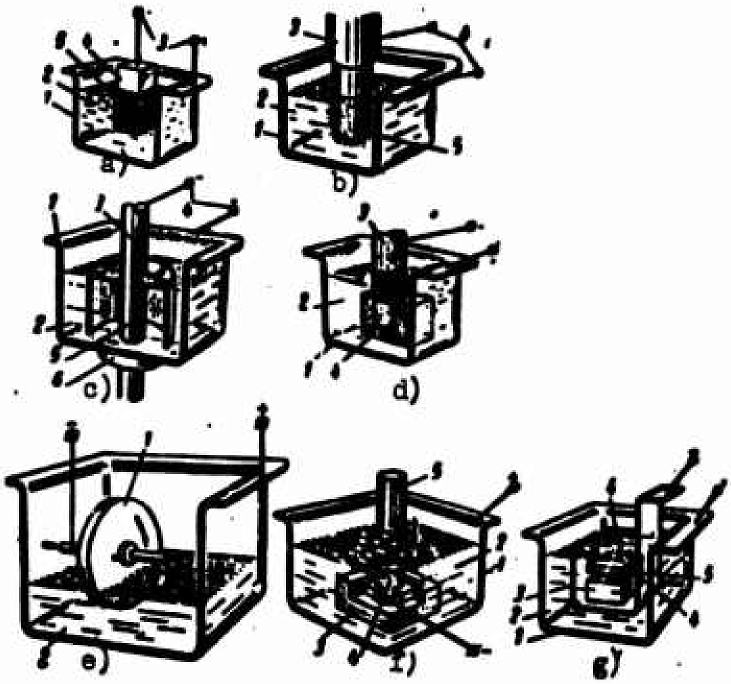

Fig. 4. Heating in electrolytes: a) fundamental circuit: 1 — bath — anode; 2 — electrolyte; 3 — current feed; 4 — part — cathode; 5 — part heated under gas film; b) diagram of general and heating: 1 — bath — anode; 2 — electrolyte; 3 — part — cathode; 4 — current feed; 5 — heated surface of part; c) diagram of general continuous heating: 1 — bath — anode; 2 — electrolyte; 3 — part — cathode; 4 — current feed; 5 — heated section of part; 6 — insulating bushing for passage of part through bath; d) diagram of local heating for hardening or annealing: 1 — bath — anode; 2 — electrolyte; 3 — part; 4 — shield; e) diagram for continuous heating of rotating body in an electrolyte: 1 — part (disk) — cathode; 2 — electrolyte; f) diagram of heating in electrolye for hot upsetting: 1 — bath — anode; 2 — electrolyte; 3 — insolator-support; 4 — heated blank — cathode in die; 5 — ram (punch); g) diagram for soldering during heating in an electrolyte: 1 — bath — anode; 2 — electrolyte; 3 — support; 4 — soldered part; 5 — solder.

Two-stage heating is most expedient at which after a certain period at increased voltages (first step) voltage is lowered (second step).

For process stability current density at the cathode should significantly exceed density at the anode.

The following operations are executed by this method: heating for surface hardening, through heating for stamping, fluxless brazing, and annealing with oxidation.

General end heating (Fig. 4b). Part 3, subject to heating, is immersed as the cathode in electrolytic bath 1, filled with electrolyte 2, through which is passed an electric current from source 4. A portion of part 5, in the electrolyte, is heated to the required temperature, and the degree of heating is regulated by duration of current flow.

General continuous heating (Fig. 4c,e).Heated part 3 is continuously moved through bath 1 with electrolyte 2 during transmission of current. The heating zone moves correspondingly.

Local heating for hardening or annealing (Fig. 4d). Sections not subject to heating are insulated with nonmetallic shields 4 (refractory brick).

Heating for hot upsetting (Fig. 4f). Blank 4, placed in an insolated die 3, which is the cathode, is heated by passing current through electrolyte 2 at a high voltage. After attaining the required temperature current is turned off and ram 5 is lowered onto the softened blank.

Soldering by heating in an electrolyte (Fig. 4g). By passing a high-voltage current through electrolyte 2, parts 4 being soldered are heated and solder 5 melts between them.

5. Electroerosion [EE], based on breakdown and removal of metal by thermal and mechanical action of an electrical gas discharge which directed on the processed section, being in a liquid medium.

Breakdown and removal of metal occurs as a result of pulsing concentrated heat emission, melting and evaporating the metal and is accompanied by significant mechanical shocks occurring as a result of decomposition of the liquid medium in zone of treatment. According to the varying time of pulsed discharge and certain variations in forming methods there are two basic methods of electroerosion treatment – electrospark [EIS] and electropulse [EIM].

Elektospark treatment [EIS] (Fig. 5a). Pulsed discharges between electrodes 5 and 6 destroy their surface (mainly the anode); the size and shape of the destroyed section is almost the same size and shape of cathode 5 that is used in different operations of controlled sizing by the electrospark method. The basis any electrospark unit is electrical circuit (Fig. 5a), generating current pulses of necessary capacity and type.

The electrospark method is used for execution of different operations, among which the basic are: reaming cavities and holes of any shape, cutting material, sharpening tools, grinding, hardening tools, applying metals, producing powders, engraving and inscribing metals, etc.

Engraving metal by inscribing (Fig. 5b). Deep engraving lines are obtained as a result of removal of metal by pulsed discharge, occurring movement of electrode (cathode) 2 on the metal surface of part 1. It is possible to engrave metals and alloys of any hardness. The surface is covered by a small layer of liquid (oil, kerosene) 3.

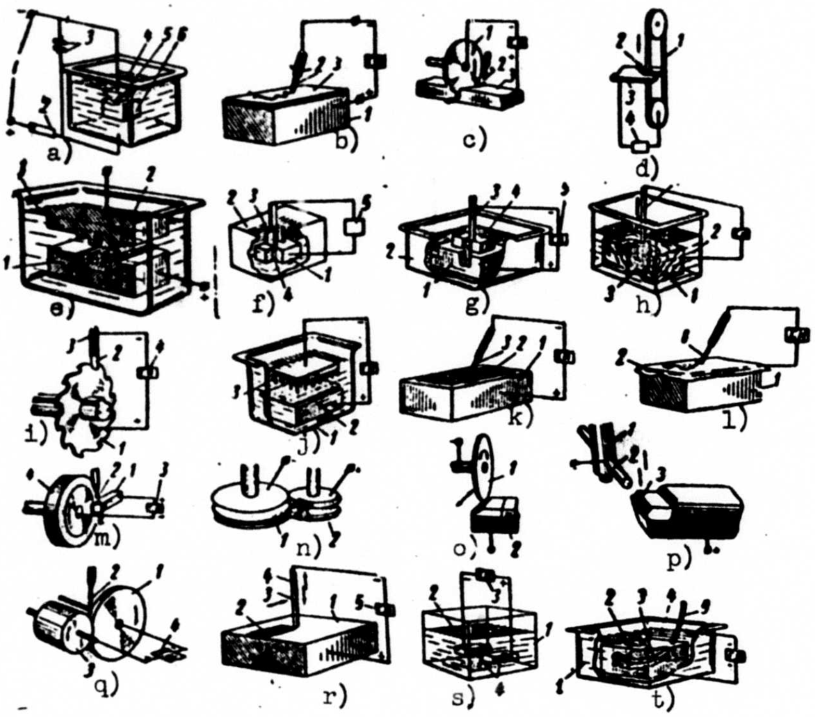

Fig. 5. Electroerosion treatment: a) fundamental diagram of electrospark variety of electroerosion treatment with use of a relaxation capicator circuit: 1 – feed of current; 2 – resistance; 3 – capacitor; 4 – liquid dielectric medium; 5 – electrode-tool; 6 – electrode-part (elements 1, 2, 3 – in all subsequent diagrams they are designated GI (pulse generator); b) engraving: 1 – article; 2 – electrode; 3 – layer of oil on surface of part; c) disk cutting: 1 – cutting disk; 2 – supply of working fluid; 3 – cut blank; 4 – current source; d) belt cutting: 1 – belt; 2 – supply of working fluid; 3 – cut blank; 4 – current source; e) electrospark broaching (copying, engraving): 1 – part – anode; 2 – electrode-tool – cathode; 3 – working liquid; f) electroerosion broaching (copying, engraving): 1 – blank (part); 2 – working medium; 3 – electrode-tool; 4 – forming cavity in part; 5 – pulse generator; g) electroerosion drilling of small holes: 1 – part; 2 – working fluid; 3 – elektrode-tool; 4 – conductor from insulating material; 5 – pulse generator; h) extraction of broken tool and mount: 1 – part with frozen fragment of tool or mount; 2 – working fluid; 3 – extracted fragment; 4 – electrode, cutting fragment; i) strengthening tools: 1 – tool; 2 – electrode; 3 – vibrator; 4 – pulse generator; j) manufacture of grids: 1 – bath with working fluid; 2 – drilled part; 3 – electrode for drilling; k) scribing on metal: 1 – part; 2 – layer of oil; 3 – engraver's electrode; l) scribing on nonmetallic materials: 1 – part; 2 – sheet of metallic foil; 3 – electrode; m) sharpening tools: 1 – sharpening cutter; 2 – supply of working fluid; 3 – impulse generator; 4 – tool-grinding disk; n) profiling of hard-alloy tool: 1 – profiling electrode; 2 – profiled tool; o) profiling of grooves by disk on hard-alloy tool: 1 – profiling disk; 2 – profiled cutter; p) profiling of grooves with fixed electrode: 1 – holder; 2 – profiling electrode; 3 – profiled groove; q) electrospark grinding: 1 – grinding disk – electrode; 2 – supply of working fluid; 3 – ground part; 4 – pulse generator; r) applying metals: 1 – part, coated with metal; 2 – applied metal; 3 – electrode; 4 – vibrator; 5 – pulse generator; s) producing powders: 1 – bath; 2 – working fluid; 3 – pulse generator; 4 – atomized electrodes; t) drilling of holes with curvilinear axis: 1 – bath; 2 – part; 3 – drilled hole; 4 – working fluid; 5 – electrode.

Engraving by printing (Fig. 5e). Print will be formed by means of a stamp-cathode 2, carring a negative image of figure to the surface of the anode metal 1. Electrical discharge between electrodes exactly reproduces figure of the cathode surface on the anode.

Reaming cavities and holes (Fig. 5f). Pulsing electric discharge, forming between face of electrode 3 and part 1, causes controlled, measured removal of the latter with formation of a hole, have the same cross section as electrode 3 and dimensions, exceeding the nominal dimension of electrode 3 by magnitude of side spaces 4. The process is produced in a liquid medium during feeding of a pulsing current from source 5.

Reaming small holes (Fig. 5g) – the process in principle is analogous to electrospark reaming but is done at specific vibration of the electrode tool or part which facilitates removal waste. Conductor 4 is made from a hard nonconducting material which is necessary for control of tool and increasing its rigidity.

Extraction of broken tool and mount (Fig. 5h). For extraction of part 1 the remainder of broken tool 3 (or mount), from a body the latter is cut into sections or atomized by an electrical discharge, directed by cathode electrode 4. Process is done in a liquid medium 2 by feeding a pulsing current to electrodes 3 and 4.

Strengthening the tool (Fig. 5i). Thermal and chemical action of electric discharge, appearing between electrode 2 and surface of tool 1, produces in the latter a sharp chemical and structural change, increasing stability of tool. To the strengthening electrode is given an oscillatory motion with the help of vibrator 3.

Manufacture of grids (Fig. 5j). A grid is obtained during electrospark piercing of sheet metal by set from separate electrodes,

located on a mandrel in accordance with location of holes in grid.

Cutting (Fig. 5c and d) is produced by action of electric discharge, appearing between moving disk (belt) – cathode 1 and article – anode 3 in medium of liquid 2 during feeding of pulsing current from source 4.

Scribing on metal (Fig. 5k) is called out similar to engraving by method of drawing, but with variable polarity of electrodes and selection of composition of applied metal for the required color of the figure.

Scribing on nonmetallic materials (glass, porcelain, ceramics) (Fig. 5l) is carried out analogous to scribing on metal, but, preliminarily, nonmetallic surface 1 is pasted to sheet foil 2, playing role of the second electrode. Discharge between cathode electrode ("pen") 3 and foil melts the latter and forces it in the base, leaving strong metallic tracings, forming an image.

Sharpening tools (Fig. 5m). A pulsing electric discharge, appearing between edge of the sharpened cutter 1, including the anode, and surface of a fast moving metallic disk 4 – cathode, in presence of liquid 2 and during feeding of current pulses from source 3, directly destroys and removes metal from edge of the cutter, producing grinding and sharpening of it.

Grinding (Fig. 5q). Removal of material from surface of ground article occurs as a result of action of pulsing electric discharge, created between moving electrode – polisher 1 and surface of part 3, including anode. Treatment is done in medium of liquid 2 during feeding of circuit with current pulses from source 4.

Applying metals (Fig. 5r). At specific parameters of discharge contour an electric discharge in air and gases is accompanied by

transfer of a certain quantity of material of anode to the cathode. By moving part 1 on the surface, electrode-anode 3, put into oscillatory motion with the help of vibrator 4, and creating a discharge between electrodes, coats surface of the part with a thin porous layer of cathode metal.

Producing powders (Fig. 5s). Pulsing electric discharge, destroying electrodes 4 in a liquid medium form products of destruction in the form of grains of different magnitude which settle in the liquid.

Drilling of curvilinear holes (Fig. 5t). Operation is conducted analogous to drilling holes and cavities, but cathode electrode 5 has curvilinear form.

Electropulse treatment [EIM] differs from electrospark by its nature (unipolarity), duration (from 100 to 1000 μsec), average and small porosity* (Q = 1-10) of impulses.

Fundamental diagram of electropulse treatment is almost analogous to diagram of spark treatment (Fig. 5a), but feeding at operating discharge by pulse current is produced not from a relaxation pulse generator (capacitor, resistance) but from independent generator, chiefly from machine, producing unipolar impulses of corresponding frequency (for instance 400 cps).

Processed article during electropulse treatment is cathode, and electrode-tool — anode.

Electropulse treatment differs significantly from electrospark by higher speeds of yield on severe and average modes by significantly smaller process energy, by comparatively small wear of tool and by a somewhat lower productivity in clean modes.

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*Ratio of period T to impulse duration t_u.

CHEMICAL-MECHANICAL METHODS OF TREATMENT

Chemical-mechanical [XM] are those methods of treatment of materials in which destruction and removal of material (correspondingly its structure change) occurs without feed of electrical energy from external current source as a result of chemical or electrochemical reactions between processed surface and environment during simultaneous mechanical influence on processed section, promoting intensification of process and removal of products of destruction formed from zone of treatment.

For purposes of sizing treatment of metals, the most widespread variety of chemical-mechanical treatment is carried out in solutions of salts of metals.

During contact of surface of metals with solutions of certain salts interactions occurs leading to dissolution of surface layer of metal. Thus, for instance, during submersion of an iron alloy in solution of copper salts a reaction occurs between them leading to displacing of copper and transition of iron into solution.

An analogous phenomenon occurs during submersion of cermet hard alloy in solution of copper salts consisting of carbide grains, bonded by metallic cobalt. Cobalt bonding is destroyed, since cobalt passes in solution, displacing copper. As a result, the hard alloy in surface layer of dissimilar metals and heterogeneity of structure promotes destruction of the hard alloy due to formation of a large number of galvanic micro pairs, between which appear local electrical currents. According to precipitation of copper from solution it covers processed surface with film and dissolution stops. In order to maintain a high rate of dissolution, the copper film is loosened with the help of friction by an abrasive powder under small

pressure (Fig. 6a).

The characteristics of certain operations are given below:

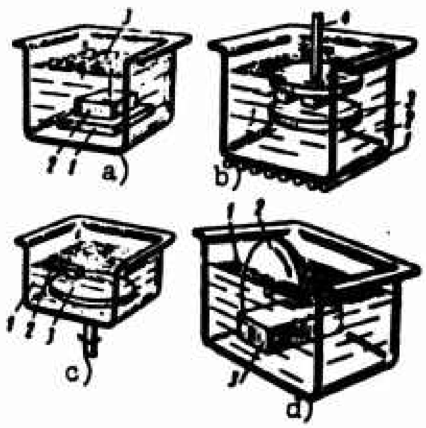

Fig. 6. Chemical-mechanical methods to treatment: a) fundamental circuit: 1 — block; 2 — ground or rubbed article; 3 — mixture of solution of salt with abrasive powder; b) grinding (finishing): 1 — heater; 2 — bath; 3 — bottom block; 4 — top block; c) sharpening hard-alloy tool: 1 — bath; 2 — cutter, equipped with hard alloy; 3 — block; d) cutting: 1 — solution of salt with abrasive powder; 2 — cutting disk; 3 — cut part.

Chemical-mechanical grinding (Fig. 6b) consists in radial shift of ground part relative to revolving flat disk 3, immersed in mixture (bath 2) of abrasive powders with solution of copper sulfate.

Chemical-mechanical sharpening of hard-alloy tool 2 (Fig. 6b) is carried out by pressing the sharpening edge to revolving disk 3, immersed in mixture of abrasive with solution of copper sulfate 1.

Chemical-mechanical cutting (Fig. 6d) is done with 2 thin metallic or abrasive disk 2, having rotary and forward movement and cutting into article 3 while in mixture 1 of an abrasive powder with solution of copper sulfate.

Electrohydraulic method of treatment (EGE). This method (Fig. 7a) is based on use of high pulsing pressures, forming in a liquid during high-voltage electric discharge of small duration, with steep front.

Passage in medium of liquid of circuit formed by high-voltage discharge evokes appearance in zone of liquid, surrounding channel of discharge, ultrahigh pressures also of a pulsing nature. Focusing and directing of pressures impulses on surface of part (blanks),

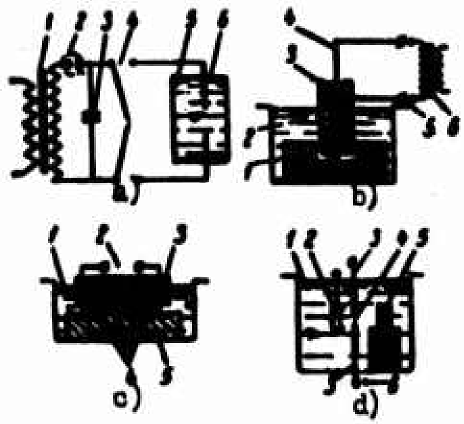

Fig. 7. Electrohydraulic methods of treatment: a) fundamental circuit: 1 — step-up transformer; 2 — rectifier tube; 3 — capacitor; 4 — forming intervals; 5 — basic interval; 6 — bath; b) piercing nonmetals: 1 — part (blank); 2 — water; 3 — external electrode; 4 — internal electrode (plate); 5 — forming intervals; 6 — step-up transformer; c) cutting nonmetals: 1 — water; 2 — basic electrodes; 3 — insulator; 4 — intermediate discharge gaps; 5 — part-blank; d) riveting: 1 — water; 2 — focusing reflector; 3 — electrodes; 4 — basic interval; 5 — part (blank); 6 — forming intervals.

produces treatment of it. Capacity and duration of pulses of pressure are determined by the parameters of the electric circuit.

This method may be used for riveting of metallic surfaces, piercing (drilling, hollowing) nonmetallic brittle materials of any hardness, cutting of nonmetallic materials, and other operations.

The fundamental circuit drilling cavities and holes in nonmetallic materials is shown in Fig. 7b. A pulsing high-voltage discharge, flowing in medium (liquid) 2 between external electrode-tube 3 and internal electrode 4, creates pulsing hydraulic impacts in volume of liquid, which destroying material of blank. Direction of destruction is determined by shape and location of electrodes. Diagram of cutting nonmetallic materials is shown in Fig. 7c. Cutting of a nonmetallic material 5 is produced with the help of hydraulic impacts, appearing near set of spark discharger plates 4, fastened in insulator 3. High voltage is brought into dischargers through electrodes 2. Longitudinal movement is used for cutting of plates. Diagram of riveting of metallic surfaces is shown in Fig. 7d. A hydraulic pulse, forming as a result of electrical spark-over in

discharge interval 4, is focused by spherical reflector 2 on metallic surface of part 5, which at this time is riveted.

CHEMICAL MILLING (DEEP CONTOUR ETCHING)

Chemical milling constitutes a process of chemical (sometimes electrochemical) treatment of metal in acid or alkali baths and is used for treatment of aluminum and magnesium alloys, steel, including stainless, titanium, copper alloys, beryllium and other metals and their alloys, utilized in industry.

With this process metal can be removed both from the entire surface of a part or also from individual sections (local etching); it can be used to produce holes of a given contour (through etching). Chemical milling allows to lower total weight of part by means of local removal of unnecessary metal, while not lowering its strength. For instance, it is possible to lighten sheet parts in unstressed or lightly stressed areas by 50-60%.

The process of chemical milling consists of four basic operations:

1) pre-cleaning of surface;

2) applying protective coatings on surface of detail at points, not to be etched;

3) etching;

4) cleaning after etching and inspector 1.

The main difficulty in realization of process of chemical milling consists in selection of protective covering, reliably protecting an area not to be etched.

The protective covering should answer the following requirements:

a) reliably protect the metal from influence of etching

solutions for a specific time;

b) to have sufficient mechanical strength and good adhesion to the processed metal;

c) not to cause corrosion of protected metals;

d) to be applied on metal with a brush, paint sprayer, rollers, glazing or dipping;

e) to be easily removed from surface of part after completion of etching.

In Tables 9-12 are given the basic operations of chemical milling with certain recommendations on compositions of baths, conditions of process, temperatures, depths of milling, applied equipment, methods of inspection, etc.

As protective coating varnish and paint coverings can be used, basically perchlorovinyl varnishes and enamels, polyamide varnishes and materials on the basis of neoprene rubbers. More rarely used are special adhesive tapes, rubber tightly pressed to parts patterns or metallic coatings, for instance, electrolytic plating with copper.

For best cohesion of coating with metal of part sometimes, in the beginning, anodic oxidation of its surface, and then application of protective paint coverings is conducted.

A break of time between application of protective covering and etching should not exceed 24 hr. In the painting section, where protective covering is applied, is recommended to have temperature 15-35°C, and relative humidity up to 75%.

Table 9. Preparation of Parts Before Chemical Milling

Processed metal	Basic operations	Used equipment	Composition of baths for cleaning and degreasing	Temperature of bath	Time of holding in mm	Note
Aluminum alloys (AMg6, D16, V95, AK-8 and others)	Degreasing	Cloth x/b Tank with cover	Gasoline B-70	–	–	It is possible to degrease in vapors of trichloroethylene with subsequent 20 minute holding in mixture of chromic and sulfuric acid; aqueous solution of sodium phosphate and others
	Light etching for removal of plated layer	Bath steel	NaOH 45-55 g/liter Sodium fluoride 45-55 g/liter	60-70	~10-15	
	Washing in warm and cold water	The same	Flowing water	40-50	To full washing	
	Brightning in nitric acid	Bath with jacket from stainless steel	Nitric acid 350-425 g/liter	–	2-5	
	Washing in cold and hot water	The same	Flowing water	≥ 50	To full washing	
	Drying	Drying cabinet	–	30-50	20	
Titanium alloys. Stainless steel	Etching for removal of scale	Steel bath lined with vinyl plastic	Flowing water acids: fluoric 50-60 g/liter, NaOH 150-160 g/liter	Room temperature	0.5	To full loosening of scale
		Bath with electric heating	NaOH, sodium nitrate 20%	450-460	15-40	Treatment of titanium at $T > 470^{\circ}C$ is dangerous due to combustion of titanium in the melt which can lead to explosion of bath and spraying of alkaline melt
	Washing in cold and hot water	Bath with jacket from stainless steel	Flowing water	≥ 50	To full washing	
	Drying	Drying cabinet	–	30-50	20	
	Degreasing	Cloth x/b Tank with cover	Gasoline B-70	–	–	
	Light etching	Steel bath	NaOH 45-55 g/liter	50-60	15-20	
	Repeated washing	The same	Flowing water	60-80	To full washing	For stainless steel blowing with metal powder
	Drying	Drying cabinet	–	80-120	10-15	

Table 10. Protective Coatings for Non-Etched Areas

Processed metal	Basic operations	Equipment	Protective				Drying of covering		Note
			Designation	Composition	Viscosity according to B3-4 per sec	Thickness	Temperature °C	Time of holding	
Aluminum alloys	Application of covering	Pulverizer p = = 3.5-4.5 atm, painting chamber	Perchlorovinyl, enamel*	Enamel PKhV-510V Solvent RS-1 TU MKhP 1848-52 Enamel KhV-16 TU MKhPKU 512-57 Solvent R-5 TU MKhP 2191-50	25-30 15-20	3 layers 3 layers (total 200-250 μ)		—	Check by external inspection of each layer of enamel
	Drying	Drying chamber	—	—	—	—	18-35	45-50 min	For each layer
	Masking for chemical milling	Knife (scalpel, needle), pattern	—	—	—	—	—	—	There should not be burrs, scratches and peeling of paint in lines of contour
	Final drying	Drying chamber	—	—	—	—	18-35 80-90	20-36 hr 2 hr	
Titanium alloys	Application of covering	Pulverizer	Glue	Paste AK-20 Diluent RDV	13-20	6 layers	—	—	Recommended: 1) to substantiate protective covering by additional irradiation with luminescent lamps or incandescent lamps (30 min), or heat in drying cabinet (80°C, 2 hr), or hold in sunlight for not less than twenty-four hours; 2) to conduct preliminary anodization at 3-10 μ for best adhesion of covering
	Drying	Drying cabinet	—	—	—	—	12	20-40 min	
	Masking for chemical milling	Knife pattern	—	—	—	—	—	—	
	Control of final drying	Drying cabinet	— —	— —	— —		60-70	2 hr	

*It is possible to apply other coverings, for instance: a) enameled perchlorovinyl: KhV-16, PKhVR-510V, solvent RS-1; b) enamel + glue: enamel PKhV-510V (1 layer), glue PFE 2/10 (2 layers), solvent — ethyl or isopropyl alcohol; c) Glue + varnish: glue PFE 2/10, varnish 548 (1:1); d) enamel: KhVE-22, KhVE-16, PKhV; e) On the basis of neoprene rubber and glue (at etching depth of 25-30 mm) and others.

Table 11. Process of Chemical Milling (Etching)

Processed metal	Equipment used	Composition of baths	Temperature in °C	Time of holding	Rate of etching in mm/hr	Depth of etching in mm	Allowed deviations in mm depending upon depth of etching: along contour	along depth
Aluminum alloys	Steel bath	Alkaline solution: NaOH 350-400 g/liter (600 g/liter max) GOST 2263-59	70-95	Depending upon etching and solution temperature	1.14-2	To 1 1-2 2-6 (max to 12)	±1.5 ± 2 ± 3	±0.08 ± 0.10 ± 0.12 - 0.18
Titanium alloys	Bath with jacket from polychorovinyl	Hydrofluoric acid 60-70 g/liter (130-140 mm^3/liter), sulfuric acid 95-105 g/liter (55-60 mm^3/liter)	18-25	Depending upon etching depth	0.5-0.6	—	—	—
Stainless steel, steel U8 and others	Bath with jacket from polychorovinyl	Nitric acid (150-160 g/liter) hydrofluoric acid (sp. gr. 1.13) 50-60 g/liter	18-25	60-30 min	—	—	—	—

Table 12. Cleaning After Etching

Processed metal	Type of covering	Basic operations	Equipment used	Composition of baths	Temperature in °C	Time of holding	Note
Aluminum alloys	Enamel (enamel PKhV-510V, KhV-16, etc.)	Washing	Steel bath	Cold and hot flowing water	50-70	To full washing	
		Soaking protective covering (film)	Steel bath	Flowing hot water	80-90	1 hr or longer	Wet, so film will not be easily peeled
		Removal of protective covering	Knife, medical glove	—	—	—	Manually, with knife, or with soft brushes in solution of ethyl acetate with gasoline (2:1)

Table 12 (Continued)

Processed metal	Type of covering	Basic operations	Equipment used	Composition of baths	Temperature in °C	Time of holding	Note
Aluminum alloys	Enamel (enamel PKhV-510V, KhV-16, etc.)	Brightening or light etching	Steel bath with jacket (from stainless steel)	Nitric acid 300-400 g/liter GOST 701-58	Workshop	2-5 min (to full brightening)	Instead of cleaning conduct light etching
			Steel bath	NaOH, 40-55 g/liter, GOST 2263-59	50-55	1-2 min	
				Sodium fluoride 45-55 g/liter, GOST 2871-45	45-50	2 min	
		Washing	Steel bath with jacket from stainless steel	Flowing water cold and hot	60-90	To full washing	
		Drying	Drying cabinet		—	—	
		Inspection	External inspection and measuring etching of depth	—	—	—	
Stainless steel	Glue	Washing	Bath with jacket from vinyl plastic and steel bath	Cold and hot flowing water	50-90	5-6 dippings. To full washing	Manually
		Removal of covering	Knife	—	—	—	
		Drying	Drying cabinet	—	80-120	10-15 min	
		Inspection	External inspection; measuring of etching depth with thickness gauge, indicator or other method				

Table 12 (Continued)

Processed metal	Type of covering	Basic operations	Equipment used	Composition of baths	Temperature in °C	Time of holding	Note
Titanium alloys	Glue	Washing	Bath with jacket from polyvinyl chloride	Cold flowing water	—	To full washing	—
			Steel bath	Hot water	50-80		
		Removal of protective covering	Knife (manually)	—	—	—	If glue is peeled badly, then hold in hot water (70-90°C)
		Light etching	Bath with jacket from stainless steel	Hydrofluoric acid 60-70 g/liter, Sulfuric acid 95-105 g/liter	Workshop	1-2 min	
		Washing	Steel bath (Jacket from polyvinyl chloride)	Cold flowing water	—	To full washing	Blow with warm air
			Steel bath	Hot water	60-90		
		Drying	Drying cabinet		—	—	
		Control	External inspection, measuring depth of etching				

Stability of protective coverings allows to obtain significant depth of etching, but practical etching is done to a depth of 4-6 mm (rarely 12 mm), since otherwise it sharply impairs accuracy of etching and quality of surface. According to foreign data the depth of etching is possible to maintain with an accuracy up to +0.05 mm and in the perimeter (contour) not less than +0.8 mm. Minimum final thickness of sheet after etching can reach 0.05 mm.

Depth of etching depends on material of part, time of part in etch bath and rate of etching. For aluminum alloys the etching rate varies from 1.5 to 4 mm/hr. It increases with increase of temperature of solution (approximately on 50-60% on every 10°C) and depends on concentration of etching solution and its purity. Control of depth of etching can be done with control samples; with the help of automatic weight control; periodic measurements of processed part, for instance, thickness gauge or indicated bracket (in production this method is unsatisfactory); and special electronic instruments.

The surface quality after etching depends on depth and conditions of etching, and also on quality of surface of detail to treatment by etching. Usually, quality of etched surface obtained is lower than quality of initial surface by 1-2 classes of purity. All dents, local scratches, and nicks with sharp outlines after etching preserve their own initial depth, but obtain a softer profile at greater depths of etching. Method of producing blanks influences quality of surface after etching, for instance, rolled material after etching has higher surface purity than extruded or stamped material cast parts after etching have sharply expressed unevenness of surface. Also preliminary heat treatment of parts influences quality of surface. For instance, hardened aluminum

alloys, subjected to aging, can be more evenly etched and have higher surface purity than materials, not previously heat treament.

The mechanical and physical properties of metals after their treatment by chemical milling (even to depth of 6 mm) practically do not change and their fatigue characteristics correspond to those properties of the same material, subjected to ordinary milling.

By chemical milling it is possible to prepare parts with very thin crosspieces, without warping or misalignment, for instance, screen filters. It is possible to conduct etching on a cone by means of gradual submersion of part in solution; to obtain profiles of stamps of complicated configuration, to conduct treatment of panels, flats, rings, sheets of variable section, covers of hatches (both flat, and single curvature), tapered linings, sheathings of single and double curvature, pipes with through apertures and other parts. Parts can then be subjected to treatments of bending, stamping, welding, riveting, etc.

During chemical milling it is recommended to position part at a distance of 250-300 mm from bottom of bath and not closer than 200-250 mm to surface of etch solution. During total etching (over entire surface) it is necessary to turn part in process of etching.

Mixing the solution at the moment of treatment of parts in etching and cleaning baths can be done with compressed air. Thereby cooling of the etching solution is also attained; it was heated due to exothermic reaction of metal dissolution. For maintaining constant temperature of the etching solution, chemical milling baths have pipe coils, through which moves (depending upon necessity) either steam or cooling water.

ULTRASONIC METHODS OF TREATING HARD MATERIALS

Essence of process. Ultrasonic treatment of hard materials constitutes mechanical processes, in which the body being treated is suspended in liquid of abrasive particle, obtaining energy from source of vibrations of ultrasonic frequency. Two types of treatment are distinguished (Fig. 8): dimensional treatment and treatment using a free directed abrasive.

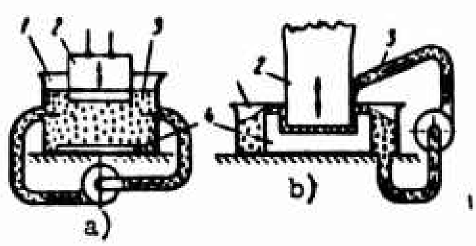

Fig. 8. Diagrams of processes of ultrasonic treatment a) free-directed abrasive; b) measured; 1 – bath; 2 – source of oscillations; 3 – suspension of abrasive; 4 – part.

In the first case the source of energy is removed from the part and treatment occurs due to the kinetic energy of abrasive grains, which obtain large accelerations due to process of cavitation, caused by propagation of ultrasonic waves in carrier liquid. Working frequencies up to 40-45 kc.

In second case face of a tool serves as source of energy, directly pressing the abrasive grains into the processed part. Working frequencies 15-30 kc.

As abrasives boron carbide, silicon carbide, diamond dust are used. Carrier liquid is water and in some cases oil.

Region of application. Ultrasonic treatment by free-directed abrasive is used for blunting of sharp edges, removal of thin flanges and dull polishing of small parts.

Measured ultrasonic treatment is used in the manufacture working shapes of hard-alloy tools, hard-alloy files, cutting dies and body stamps for small parts, parts of glass, quartz, fluorite, barium titanate, porcelain and special ceramics; for treatment of parts of

ferrite, special cermet materials, industrial diamonds, natural and artificial precious stones, and also exact shallow openings, shaped profiles in steel cyanided and nitrided parts. Ceramics and abrasive materials of certain forms can be processed without suspension of abrasive. In this case chipped particles of material promote its further treatment, being replaced by grains of abrasive.

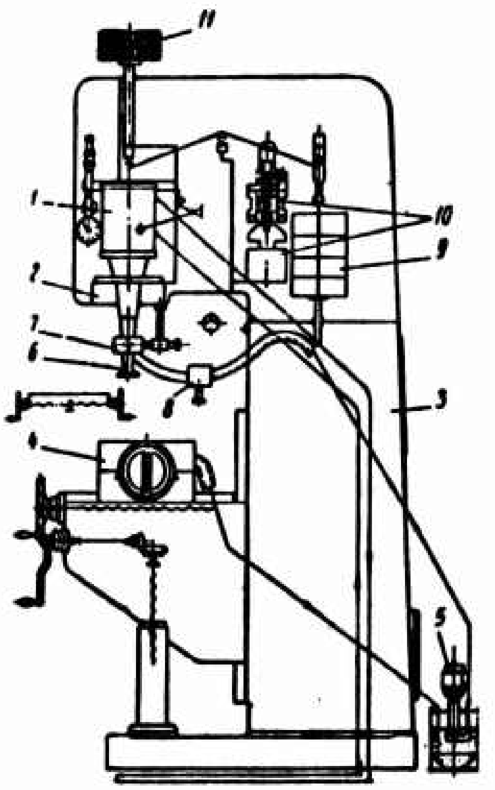

Fig. 9. Diagram of device of universal ultrasonic machine for treatment of hard and brittle materials: 1 – converter; 2 – carriage; 3 – frame; 4 – table with bath; 5 – pump system; 6 – tool; 7 – annular shower for suspension; 8 – hose with valve for adjustment of suspension supply; 9 – balancing load; 10 – electromagnet with oil shock absorber; 11 – operating loads.

Ultrasonic treatment of soft materials, such as lead, copper and soft grade of steel is unsuitable.

Machines and equipment. In machines (Fig. 9) for ultrasonic treatment of hard and fragile materials magnetostrictive converters (Fig. 10) are mainly used. Also machines with piezoceramic converters are known.

Magnetostrictive converters in most cases have a magnetic drive of O-shape form, consisting of thin (0.1-0.2 mm) annealed and oxidized plates of nickel, ferrocobalt (alloy K50F2, so-called Permendur), ferroaluminum (alloys Yu10, Yu14), possessing ability to change its dimensions in magnetic fields. Ends of magnetic drive, with square forms are brazed to the base of the transformer of elastic oscillations (Fig. 11). The latter serves to

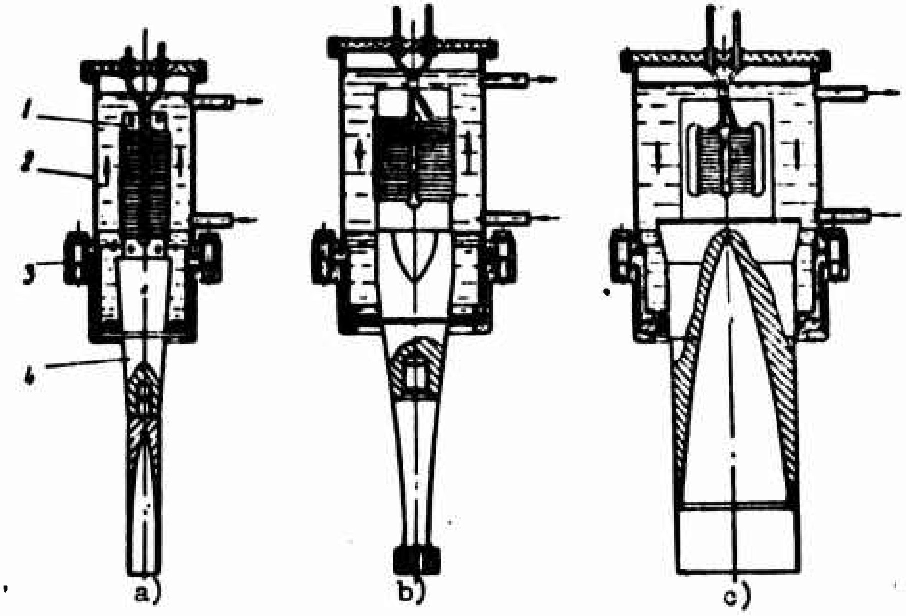

Fig. 10. Magnetostrictive converters for ultrasonic treatment: a) rating up to 1.5 kva, tool is annular type with internal formed exponents; b) rating up to 2.5 kva, tool of catenoidal form; c) rating up to 3.5 kva with transformer of elastic oscillations, having internal cavity in form of an exponent ring type tool: 1 — core with winding; 2 — cooling housing; 3 — transformer; 4 — tool.

increase amplitude of oscillations of tool (usually a few times) as compared to amplitude of the ends of converter itself, which at resonance does not exceed 5-10 μ.

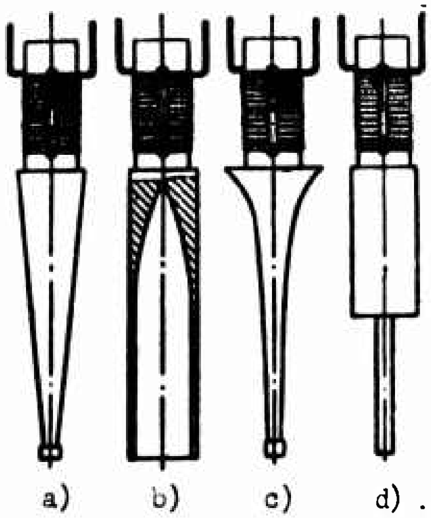

Fig. 11. Transformers of elastic oscillations: a) conical form; b) with internal formed exponents; c) with external formed exponents; d) step form.

In connection with the fact that magnetic drive and windings of the converter during operation are heated, placed in a water-cooled housing, which is fixed on the carriage of the machine. Most machines have three

regulated motions of the table in three mutualty perpendicular directions. For timely ceasing of process of treatment auto stops are used, effected from transducers, connected with depth gauges.

Feed of abrasive suspension is produced by the circulating pump system and by similar systems, used in metal-working machines for supply of emulsion. The basic technical characteristics of domestic machines and generators for their feeding are given in Tables 13 and 14.

In special forms of treatment, machines are equipped with different attachments: for rotation of processed part around certain axis, in particular case of coinciding of tool with axis for shifting part in horizontal plane, for treatment by scribing (Fig. 12) and so forth.

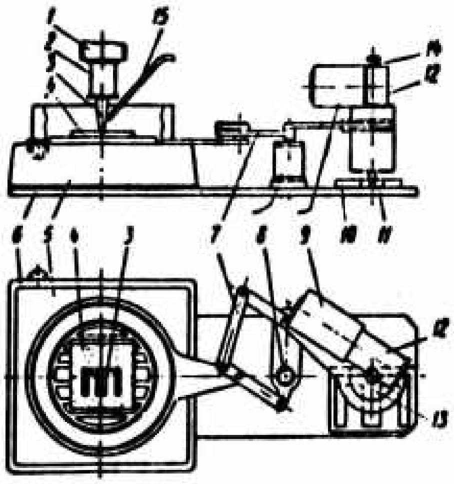

Fig. 12. Scribing device for ultrasonic treatment of parts by contour: 1 — machine carriage; 2 — converter; 3 — tool; 4 — processed part; 5 — table with bath; 6 — base; 7 — pantograph levers; 8 — revolving support; 9 — motor; 10 — scribe; 11 — magnetic roller; 12 — reductor; 13 — magnetic clutch; 14 — handle for raising magnetic roller from scribing groove; 15 — pipe and hose for supply of suspension to zone of treatment.

Technology. Productivity, accuracy and cleanliness of treatment depend on material properties (mainly from hardness and brittlness), dimensions of processed hole, form and granularity of applied abrasive and operating conditions of tool.

The basic parameters of a process are: amplitude and frequency of tool oscillations, force of supply (force in kg, with which tool presses on processed part in the absence of ultrasonic oscillations), granularity and concentration of abrasive in suspension. Parameters are mutually related and can be changed in process of treatment.

Table 13. Technical Characteristics of Native Universal Ultrasonic Machines

Machine	Producer	Model type	Output power in kw	Working frequency and range in kc	Productivity in mm^3/min per glass	Productivity in mm^3/min per hard alloy	Optimum area of tool in mm^2	Diameter of processed hole in mm	Dimensions of table in mm	System of head feed	Note
Experimental universal		P-3371	0.2	20.5 (18.5-22.5)	100-600	To 8	19.6	—	—	Counterweights	Converter from nickel, semiautomatic machine
Industrial universal	Moscow-sovnarkhoz	4770	0.25	18 (15-21)	To 300	To 8	50	—	200 × × 120	Asynchronous servomotor	Machine of table type; weight-145 kg
Industrial specialized	NITI	YZS-3	1.0-2.0	19.5 (19-22)	—	—	—	—	180 × × 180	Counterweights table	Machine of table type; weight near 80 kg
The same	NITI	YZS-3M	1.0-3.0	20 (18.5-22)	200-600	—	—	—	180 × × 150	The same	Converter of Permendur, type PMS-1
Industrial universal	ENIMS Moscow	4772	1.0	22	800	—	706	—	280 × × 200	Electronic regulator	Converter from Alfera 10-14
The same	ENIMS Moscow	4772-a	1.5	22	1000	—	700-800	—	350 × × 250	Electromagnet	Generator UZM-1.5 designed by OKBETO
The same		YZS-2	1.0	13-27	—					Counterweights	Converter from nickel
The same	NITI	YZS-1	0.5-1.5	20	—	25	190	2-80	600 × × 260	The same	Converter from permendur, type PMS-1, rise of pneumatic carriage
Industrial universal for treatment of hard alloys	NITI	YZS-1M	From 1.0 to 2.0	20	—	30	200	2-80	600 × × 250	Counterweights Electromagnet	Converter from permendur, type PMS-1M, rise of carriage with hydraulic damper
Experimental universal	Leningrad sovnarkhoz	1-YZS	From 1.0 to 2.4	20	—	5	—	—	—	Counterweights	In machine automatic rise of head and oscillating movement is provided
Experimental universal for treatment of hard alloys	NITI	YZS-4	2.0-8.0	20 (18-22)	—	—	—	To 50	—	Counterweights	Periodic tap of tool provided

Table 13 (Continued)

Machine	Producer	Model type	Output power in kw	Working frequency and range in kc	Productivity in mm^3/min		Optimum area of tool in mm^2	Diameter of processed hole in mm	Dimensions of table in mm	System of head feed	Note
					per glass	per hard alloy					
Industrial universal	ENIMS Moscow	4773	4.0	18	–	–	–	3-60	–	–	–
Specialized for treatment of hard alloys	NITI	YZS-5	1.0	18-22	–	–	–	To 50	–	Counter-weights	Supply is carried out by moving table
Experimental universal (precision)	Leningrad sovnarkhoz	2YPS	1-3	16.5	–	–	–	–	–	–	Shift heads, periodic tap of tool
Special	Moscow sovnarkhoz	ME-11	0.25	18-19	–	–	–	–	–	–	For treatment of semiconductor materials
Special	NIIKa	YZA-1	0.5	18-20	–	–	–	From 0.1	–	–	For treatment of diamond draw plate
Special	TsNILKS Leningrad	YZS-5M	0.1	24	–	–	–	–	–	–	For treatment of semiprecious stones

Table 14. Technical Characteristics of Industrial Ultrasonic Generators

Parameters	YM1-0.1	YM1-0.4	YZM-1.5	YZG-2.5	YM1-4	YZG-5	YZM-10	YZG-10
Nominal output power in kw .	0.1	0.4	1.5	3	4	6	10	9
Voltage of feed circuit in v	220	220	220/380	220/380	220/380	220/380	220/380	220/380
Number of phases of feed circuit	1	1	3	3	3	3	3	3
Maximum capacity, consumed from circuit, in kw:								
three-phase current . . . . single-phase current	 0.4	 1.0	2.5 1.0	7.5	1.0	13	14 1.5	19
Capacity of anode transformer in kva	0.3	0.9	2.5	7.5	8	12.5	11-15	18
Rectified anode voltage in kv	0.8	1.5	3.0	5	3.7	5	5	8
Type of transformer tubes .	GY-50	GK-71	GY-81	GY-5A	GY-5A	GY-51	GY-5A	GY-10A
Quantity of transformer tubes	2	2	2	1	2	2	2	1
Excitation	Independent			Self-excitation				
Working frequency in kc . .	16-24	18-30	18-30	18-25	16-24	18-25	18-30	18-24
Voltage output in v	20	80	250	450	500	450	500	500
Polarization current (max) in amp	3	10	10	40	20	40	30	60
Voltage of polarization (max)	15	5	5	4	10	8	10	
Cooling of generator tube .	Natural air flow	Forced air		Forced water and air				
Expenditure of cooling water in liter/min	—	—	—	6	8	8	4	10
Dimensions in mm:								
in plan . . . . height	310 × 340 220	470 × 420 560	600 × 660 1450	700 × 550 1400	920 × 630 1660	750 × 640 1750	1180 × 1145 2000	750 × 640 1820
Weight of installation in kg	25	75	275	350	350	500	850	600

Optimum conditions are determined also as to shave of tool, method of suspension feed and given depth of treatment.

Productivity. As long as sizes of abrasive grains remains less than oscillation amplitude of tool, productivity (in mm^3/min) increases with increased-heat measured characteristic of abrasive. In the process of work the abrasive wears out, sharp edges of grains are dulled, grain becomes smaller, and carrier liquid of suspension is contaminite by chipped particles of processed material. This leads to a drop of productivity. During noticeable impairment of quality of suspension it will heed replacement.

For determination of productivity it is necessary to multiply rate of treatment (mm/min) by area of processed hole (mm^2) or by area of working part of tool.

Depending upon depth, shape and size of processed hole, speed, and, consequently, productivity of ultrasonic treatment can be changed in wide limits. Speed of treatment grows with increase in amplitude of oscillations of tool (Fig. 13). However increase of amplitude is limited by fatigue strength of material from which tool is made. Limiting permissible amplitude of oscillations is 50-60 μ.

At constant amplitude of oscillations of tool, rate of treatment increases with increase of frequency (Fig. 14). According to measure of deepening of tool condition of feed of abrasive in zone of treatment worsen as a result of which rate and productivity of process drop (Fig. 15).

Every area and shape of processed hole fully corresponds to a definite force of supply of tool at which rate of treatment is maximum (Figs. 16 and 17).

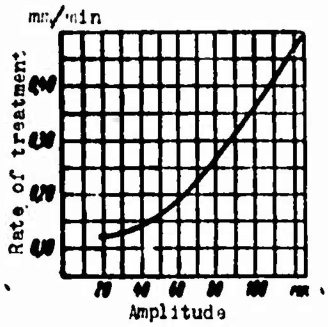

Fig. 13.

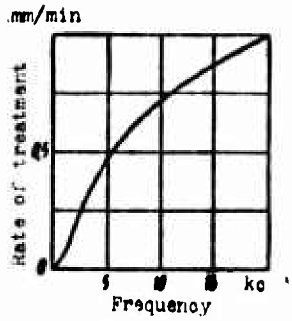

Fig. 14.

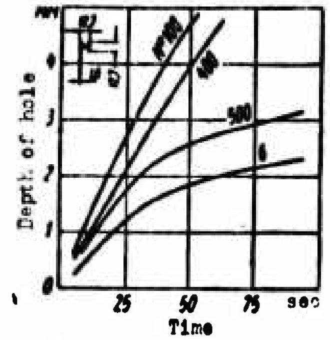

Fig. 15.

Fig. 13. Relationship of rate of ultrasonic treatment of glass to amplitude of oscillations of tool.

Fig. 14. Relationship of rate of ultrasonic treatment of glass to frequency of oscillations of tool.

Fig. 15. Relationship of depth of hole in glass to time of ultrasonic treatment at different granularity of abrasive. Shaped tool.

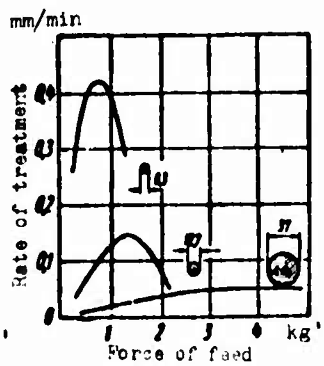

Fig. 16.

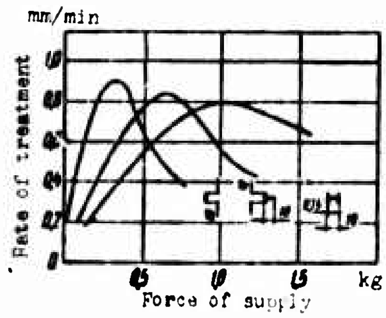

Fig. 17.

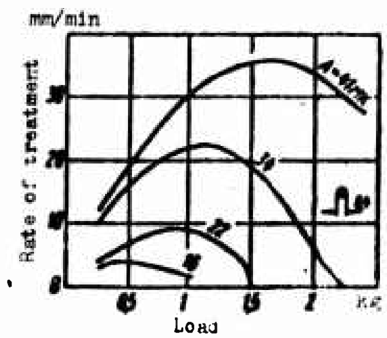

Fig. 18.

Fig. 16. Relationship of rate of ultrasonic treatment glass with cylindrical tool to force of feed at various areas of treatment.

Fig. 17. Relationship of rate of ultrasonic treatment of glass with tool of varying shave at various forces of supply.

Fig. 18. Relationship of rate of ultrasonic treatment of glass to force of supply at different amplitudes of oscillations. Frequency 20 kc. Diameter of tool 6.4 mm.

With growth of amplitude of oscillations of tool value of optimum force of supply increases (Fig. 18). Relationship of depth of hole to time of treatment at different forces of supply is shown

in the graphs of Fig. 19. Relationship of speed of treatment to dimensions and material of grains of abrasive is shown in graphs of Fig. 20.

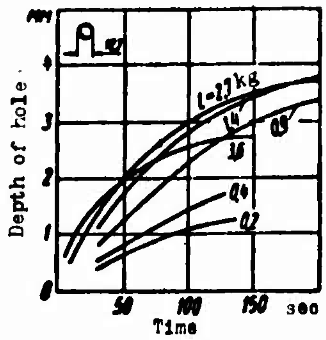

Fig. 19. Relationship of depth of hole in glass to duration of ultrasonic treatment at different forces of supply; round tool, diameter 12.7 mm.

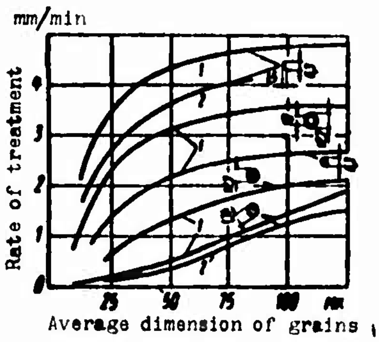

Fig. 20. Relationship of rate of ultrasonic treatment to dimensions and material of grains of abrasive at optimum forces of supply. Amplitude of oscillations is 50 μ: 1 — boron carbide; 2 — silicon carbide.

Accuracy. Accuracy of treatment is affected by the following basic factors: accuracy of manufacture and degree of tool wear granularity and quality abrasive, and also presence of transverse oscillations of tool. In the absence of transverse oscillations of tool, accuracy of treatment does not depend on diameter of processed hole. In industrial conditions, accuracy of treatment of through holes, as a rule, is 0.01-0.02 mm, attaining in separate cases ±0.005 mm. In the treatment of deep holes and external surfaces cavitational wear of tool also influences accuracy.

Surface purity. Depending upon magnitude of grain and composition of carrier liquid magnitude of microroughness is changed, which usually corresponds to an 8-9 class of surface finish. Macroroughness has the character of erosional flaws, caused by cavitational processes. Internal stresses have a large significance, in particular, at places of riveting from accidental blows in process of manufacture and finishing of tool. For a uniform structure of processed material and tool, and also at high speeds of treatment

with abundant feed of fresh abrasive, it is possible to avoid erosional flaws. Purity of treatment of lateral surfaces on the average is two classes lower than purity of face surface. With growth of hardness of material, purity of its treatment also increases.

Tool. Most often tools are made for one purpose with a transformer of longitudinal elastic oscillations of half-wave length. Here the frequency of its own elastic oscillations coincides with the working frequency of the converter.

For tool the ordinary use carbon and low-alloy steels (45, 50, 40X, 65G, 60S2 and so forth), as a rule, without heat treatment. Working part of tool should be prepared, so that axis of magnetic drive, converter and transformer elastic oscillations pass through center fittings of tool. Otherwise, transverse oscillations appear in system sharply lowering accuracy of treatment of given profile (Fig. 21).

Due to lateral wear of tool and impairment of conditions of feed of fresh abrasive in the working zone (end of tool) with increased depth of treatment a conical hole is obtained and sharp edges of face are dulled.

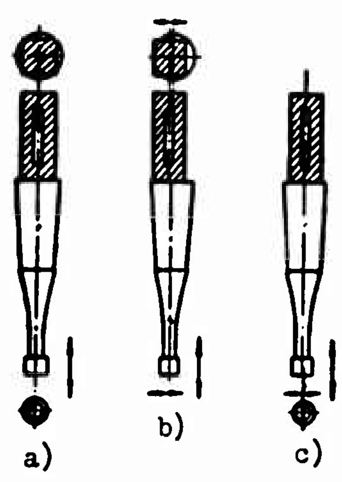

Fig. 21. Effect of coaxialness of elements of oscillatory system on formation of transverse oscillations: a) mass centers of converter, transformer of elastic oscillations and tool lie on one axis – transverse oscillations are absent; b) mass center of converter is displaced to the left – transverse oscillations are observed; c) mass center of tool is displaced to the right – transverse oscillations are observed.

For increasing accuracy of treatment is done after several passages by two, and sometimes three tools, all approximating its own dimensions to the given dimensions of profile of hole. In each subsequent passage smaller abrasive is made. Height of working part of tool makes thickness of processed part of consistent magnitude to butt wear of tool.

Wear of tool (Table 15) depends on thickness of cutting edge, and also on material, from which it is made. Tool of plastic material wears out slower. However, with growth of plasticity loss of energy by internal friction is increased. Dimensions of contour of working part of tool are established experimentally, depending upon the practically obtained gap between tool and walls of processed hole. This gap is near to maximum dimensions of applied abrasive. Thus, for instance, for gain No. 220 this gap is near 75 μ.

Table 15. Longitudinal and Transverse Wear of Tool from Various Materials During Treatment of VK-4 7.5 mm Thick with Boron Carbide No. 120

Material of tool	Form of tool	Dimensions in mm		Wear in length in mm
		before treatment	after treatment	
Steel 20	Ring ϕ6 mm . .	ϕ8.01	ϕ7.96-7.99	5.8
Steel 45	Ring ϕ8 mm . .	ϕ8.5	ϕ8.44-8.46	5.8
Steel 65G	Tetrahedron .	73 × 6.75	6.19 × 6.20	5.9
Steel 20	Hexahedron . .	7.5	7.60	5.5
Brass L5S	Ring od. ϕ6 mm	ϕ8.48	ϕ8.41-8.48	9.2

With increase of force of supply the difference in dimensions of tool and processed hole decreases.

Transverse wear of tool is 0.04-0.5 mm on diameter. For

tools from steel with carbon of content 0.2-0.5% longitudinal wear is 60-80% of thickness of processed hard alloy.

ULTRASONIC PURIFICATION

Excitation of ultrasonic oscillations in liquid media is used for purification of parts. In addition quality is improved significantly and time of process is reduced.

In the range of low ultrasonic (ten kilocycles) and high sonic (10-20 kc) frequencies a large influence on process of purification is rendered by cavitation. Closing of cavitational bubbles evokes local hydraulic blows, which directly influence contaminations. During purification, the widely used oscillations with a frequency 18-40 kc.

Methods of ultrasonic purification, liquids used, construction and characteristic of equipment depend on dimensions, form and material of parts, and also on composition and properties of removed products.

Purification of parts from grease and mechanical contaminations. Ultrasonic purification of parts, especially with complicated form of surface, for instance, with deep and threading of holes, grooves, and so forth, is very effective and allows almost completely to remove grease and mechanical contaminations.

Ultrasonic purification usually continues from several tens of seconds to several minutes depending upon composition and properties of contaminants.

Most contaminators are hydrophobic substances, i.e., they are not moistened by water and are not dissolved in it. Therefore, purification of parts requires application of special washing media,

the effectiveness of which is increased due to influence of ultrasonic oscillations.

During ultrasonic purification both water solutions of alkalis and surface active materials and organic solvents are used.

Water solutions of alkalis are effective washing media. They are cheap and do not require application of complicated equipment. Ultrasonic purification in water solutions of alkalis is widely used before coating of parts. However, these solutions interact with metals, in consequence of which they are not used when it is necessary to completely exclude possibility of corrosion of purified parts without resorting to passivation of surface.

During ultrasonic purification can enter caustic alkalis, carbonates and phosphates (Table 16) in composition of washing solutions. Of the caustic alkalis, they commonly use NaOH (GOST 2263-59), of the carbonates — calcinated soda (GOST 5100-49), of the phosphates — trisodium phosphate (GOST 201-58). Especially effective are solutions of trisodium phosphate. They render an emulsifying action, which is strengthened during excitation of ultrasonic oscillations in bath. Trisodium phosphate is adsorbed on particles of contaminations, promoting their breaking away from cleaned surface and preventing reverse precipitation.

Washing liquids have to possess high surface activity and ability to form strong adsorptive layers. For this purpose during ultrasonic purification in alkali solutions they introduce synthetic surface active materials OP-7 or OP-10, which are polyethylene glycol esters of alkylphonols.

Table 16. Compositions of Alkali Solutions Used in Ultrasonic Purification

Composition of solution	Concentration in g/liter	Cleaned metals
Calcinated soda*. . .	12-28	Steel
Trisodium phosphate*.	5-10	
Sodium silicate*. . .	15-30	
Sodium hydroxide* . .	5-25	
Calcinated soda*. . .	3-20	
Trisodium phosphate*.	3-20	
Sodium silicate*. . .	3-20	
OP-7*	3.5	
Sodium hydroxide**. .	15-20	
Potassium bichromate**	1.5	
Sodium hydroxide. . .	5-10	Steel, copper, brass
Calcinated soda . . .	15-30	
Trisodium phosphate .	30-60	
OP-7	3-5	
Trisodium phosphate .	30-40	
OP-7	3-5	
Calcinated soda . . .	10	Steel, aluminum
Sodium silicate . . .	10	
OP-7	3	
Calcinated soda . . .	3	Brass
Potassium bichromate.	0.5	
Calcinated soda . . .	3	
Trisodium phosphate .	3	
Potassium bichromate.	0.5	
OP-7 or OP-10	3	
Calcinated soda . . .	4	Copper aluminum, zinc
Trisodium phosphate .	6	
Sodium silicate . . .	10	
Trisodium phosphate .	5	Aluminum, zinc
OP-7 or OP-10	3	
Calcinated soda . . .	5	Magnesium and its alloys
Trisodium phosphate .	5	
OP-7 or OP-10	3	
Aqua ammonia	30	Gold and its alloys
OP-7 or OP-10	3	

*Used for purification of strongly contaminated parts.
**Used for purification simultaneous with passivation.

For decreasing viscosity of contaminations and increasing effectiveness of action of solutions, temperature of bath should be 55-60°C. Heating of solution occurs partially or completely due to absorption of ultrasonics energy.

The variety of solutions is noted by both distinction in properties of contaminations, and corrosion stability of cleaned metals with respect to alkalis. Least stable are aluminum, copper, zinc, magnesium and their alloys, owing to which during purification of these metals a high concentration of alkalis in solution is not permitted.

After ultrasonic purification of part wash in hot water and blow dry with compressed air. Steel parts, during necessity, are passivated in sodium nitrite. If contamination is very binding (as, for instance, remainders of polishing paste), then before purification of part, dip in hot water.

Quality of ultrasonic purification in alkali solutions usually is controlled in industrial conditions according to method of wetting. In laboratory conditions it is possible to apply more exact and sensitive methods – photometric, fluorescent, radioactive.

Organic solvents (Table 17) practically do not interact with metals, are used primarily during ultrasonic purification of parts of complicated and precisions mechanisms before assembly. Their selection is determined by composition and properties of removed contaminations. Contaminations, containing mineral oils, clean in hydrocarbon solvents (in particular, gasolines) and their derivatives (chlorinated solvents). Vegetable oils, containing acids from hydroxyl groups, and also natural resins, containing oxygen compounds, clean in alcohols.

Table 17. Compositions and Properties of Organic Solvents Used for Ultrasonic Purification

Designation of solvent	Density at 20° in g/cm³	Temperature in °C			Explosive concentration in mixture with air in %
		boiling point at 760 mm Hg	flash point	self-ingition	
Combustible solvents					
Gasoline "galosha" . . .	0.722	80	-17	350	1.1-5.4
Gasolines of other types	0.70-0.76	40-180	From -50 To +30	415-530	1.0-6.0 (gasoline B-70 2.5)
Acetone	0.792	56	-15	570	12.9-13
Ethyl alcohol	0.789	78	From +9 To +32	510-586	3.5-18
Benzene	0.874	80-81	-8	-	2.81
Incombustible solvents					
Tetrachloroethane . . .	1.603	145.5	-	-	-
Pentachloroethane . . .	1.688	159.5	-	-	-
Trichloroethylene . . .	1.470	86.7	-	-	-
Tetrachloroethylene . .	1.62	120.8	-	-	-
Carbon tetrachloride . .	1.59	76.5	-	-	-

From incombustible chlorinated solvents the most widely used for ultrasonic purification are ethylene trichloride and tetrachloride and carbon tetrachloride and from fuels — "Galosha" gasoline (GOST 443-56), and gasoline B-70 (GOST 1012-54). Purification is also done in alcohols — methyl (GOST 2222-60) and ethyl (VTU L4-60-54) and their mixtures with acetone (GOST 2768-60).

Purification of parts in organic solvents is usually done consecutively in two or three baths. At especially high requirements for quality purification of parts after treatment in ultrasonic bath, they are washed under shower and placed in bath of solvent vapors and then dried.

Purification of parts from products of corrosion. Influence of ultrasonics is used for direct removal of both corrosion products, and etching products — slime.

Table 18. Solutions of Acids, Used in Ultrasonic Purification

No.	Composition of solution	Concentration	Cleaned metals
1	Sulfuric acid (specific gravity 1.84)	100 ml/l	Carbon steel
	Hydrochloric acid (specific gravity 1.14) .	50 ml/l	
	Petrov's contact	30 g/l	
2	Sulfuric acid (specific gravity 1.84)	110 ml/l	The same
	Sodium chloride	60 g/l	
	Addition KS	10 g/l	
3	Nitric acid (specific gravity 1.35)	100 ml/l	Stainless steel
	Potassium fluoride or sodium fluoride	45 g/l	
4	Nitric acid (specific gravity 1.35)	100 ml/l	
	Hydrofluoric acid (40%) .	50 g/l	
5	Sulfuric acid (specific gravity 1.84)	120 ml/l	
	Potassium bichromate . .	30 g/l	
	Sodium chloride	10 g/l	
6	Nitric acid (specific gravity 135)	100 ml/l	Stainless steel
	Sulfuric acid (specific gravity 1.84)	50 g/l	
	Hydrofluoric acid (40%).	50 g/l	
7	Sulfuric acid (specific gravity 1.82)	180 ml/l	Alloys of titanium (VT-1, OT-4)
	Ammonium chloride	50 g/l	
	Calcium fluoride	5 g/l	
8	Hydrochloric acid (specific gravity 1.14).	650 ml/l	Alloys of titanium (VTU-1, OT-4)
	Potassium fluoride . . .	50 g/l	
9	Hydrochloric acid specific gravity (1.14).	530 ml/l	Alloys of titanium (VT-1, OT-4)
	Nitric acid (specific gravity 1.35)	50 ml/l	
	Sodium fluoride	50 g/l	

Note: 1. Temperature of solutions is 45-50°. Heating usually occurs by absorption of energy of ultrasonics.
2. Cleaning in solutions No. 3 and No. 4 flows faster than in solutions No. 5. However in solutions No. 3 and No. 4 etching of the base metal can be observed, but in solution No. 5 only the scale.
3. Solution No. 6 is very aggressive, used during removal of the tightest scale.
4. In solutions No. 8 and No. 9 etching of the base metal can occur, in solution No. 7, etching of metal is not observed.

Etching with influence of ultrasonics continues usually tens of minutes, and only thin oxidized films are removed in several minutes. Solutions of acids, used in ultrasonic purification, are given in Table 18.

Ultrasonics, rarely used applied directly in process of etching, because of the absence of sources of oscillations, possessing high cavitational and corrosional stability in solutions of acids. Protection of sources of oscillations by acid-resistant partitions essentially lowers effectiveness of influence of ultrasonics in zone of purification.

Ultrasonic purification of parts from slime is done in water after preliminary picking in solutions of acids (without excitation of ultrasonics). This method is effective in purification of parts of complicated form, and also with hardly accessible holes (long tubes).

Influence of ultrasonics is used also in purification of parts from fluxes after brazing. This operation is produced in weakly concentrated solutions of acids.

Along with activation of ultrasonic oscillations in the liquid they use contact method of purification from products of corrosion, slime and fluxes, at which oscillation is directly activated in walls of parts by pressed converters to it.

Purification of details from carbon deposits. Carbon deposits in general, and especially scales, pertain to the most difficult removed contaminations, since carbon is insoluble. Therefore in purification there occurs dissolution of the other deposited parts of an interaction of liquid with the base material of part that leads to desegregation of pieces of deposit and weakening of their

bond with the cleaned surface.

Selection of liquid depends on composition of deposit and properties of base material. Apply alkali solutions and organic solvents (see Tables 16 and 17), solution of chromium anhydride (15-20%), alcohol-acid solution (orthophosphoric acid 5%, ethyl alcohol 70%, water 25%).

Ultrasonic purification continues usually tens of minutes. However, upon removal of tight layers of scale the influence of ultrasonics turns out to be ineffective even in a mode of intense cavitation. For best removal of a carbon deposit (in particular from internal surfaces) use contact method of ultrasonic purification.

Purification of details from varnish and paint coverings is done in organic solvents (Table 17). Influence of ultrasonics is effective in the removal of paints, enamels, and resins.

Installation for ultrasonic purification. Installations for ultrasonic purification consist of sources of oscillations, sources of supply and technological equipment.

Sources of oscillations during ultrasonic purification are usually electromechanical, piezoelectric and magnetostrictive converters (see p.).

Piezoelectric converters are made from barium titanate (frequency of oscillations higher than 40 kc) or quarts frequency several hundred kilocycles).

Sources of supply of converters are a-c generators of ultrasonic frequency (UZG-10, UZM-10, UZG-5, UZG-2.5, UZM-1.5). Both angle-stage and multistage vacuum-tube oscillators are used.

Technological equipment for ultrasonic purification is executed in baths (Fig. 22, Table 19), stands and assemblies. In baths of

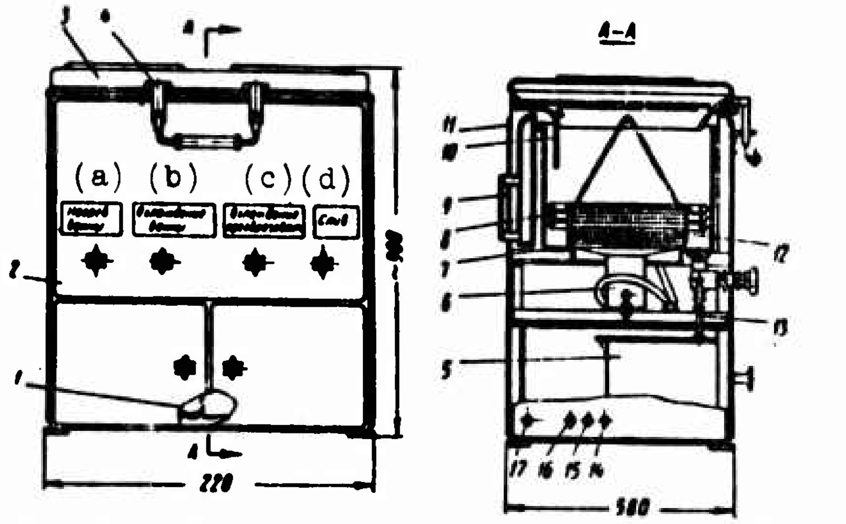

Fig. 22. Diagram of bath device UZV-16 for ultrasonic purification of parts: 1 — terminal box; 2 — soundproof housing; 3 — cover; 4 — lock; 5 — tank for overflow of liquid from bath; 6 — magnetostrictive converter; 7 — bath; 8 — coil for heating or cooling of liquid in bath; 9 — outlet in system of ventilation; 10 — thermometer; 11 — device for exhaust; 12 — screen with cleaned parts; 13 — tube for overflow of liquid from bath; 14 — pipe for supply of hot water; 15 — pipe for overflow of water; 16 — pipe for supply of cold water; 17 — pipe for introduction of electric leads.
KEY: (a) Heating of bath, (b) Cooling of bath; (c) Cooling of converter; (d) Runoff.

type UZV with magnetostrictive converters, built-in at bottom, the exhaust and soundproof housing with swinging cover.

Baths are intended for purification of part from grease and mechanical contaminations in water solutions of alkalis and in organic solvents.

In assemblies for ultrasonic purification several operations are carried out. During removal of grease and mechanical contaminations in water solutions of alkalis they usually apply preliminary washing, ultrasonic purification, washing in hot water (in particular under shower), interoperational protection by inhibitors of corrosion, and drying. During work in organic solvents, after operations of ultrasonic purification of parts, they enter shower device, vapor

bath (in vapors of solvent) and in drying chamber.

Table 19. Technical Characteristics of Bath for Ultrasonic Cleaning

Characteristics	Types of baths			
	UZV-15	UZV-16	UZV-17	UZV-18
Quantity of built-in magnetostrictive converters PMS-6M	1	2	3	4
Total area of diaphragms of converters in mm^2	300 x 300	300 x 600	300 x 900	300 x 1200
Internal dimensions of bath in mm:				
length	400	700	1100	1400
width	400	450	450	450
height	200	300	300	300
Height of bath from bottom to cover in mm .	270	370	370	370
Operating capacity of bath in liter	35	80	120	150
Useful area of bath in mm^2	310 x 390	370 x 670	370 x 960	370 x 1250
Required capacity in kw*.	2.5	5.0	7.5	10.0
Frequency of oscillations in kc	19-20	19-20	19-20	19-20
Supply voltage* in v .	420	420	420	420
Polarization current* in amp	25	25	25	25
Expenditure of water for cooling of converters in liter/min	3	6	9	12
Expenditure of water for cooling of bath in liter/min	6	8	9	10
Expenditure of air in system of draw ventilation in m^3/hr	350	750	950	1300

*Nominal values for usual operating conditions.

In most assemblies, shift parts from one position to another is mechanized, however, in certain installations (intended mainly for small-scale production) these operations are executed manually. In mass production highly productive assemblies with linear positioned conveyors and movement of parts by several parallel streams are used. For purification of small parts assemblies of the rotor type have been developed, in which special lifting-turning mechanism (with pneumatic or electrical drive) transfers grid with parts consecutively from one position to another. In certain assemblies, for improvement of quality of purification, agitating and rotation of details is done.

Besides universal baths, they use special baths and stands for ultrasonic purification of a specific narrow group of parts.

COMBINED METHODS OF TREATMENT

Along with the above-mentioned methods of electrical, chemical and chemical-mechanical treatments, number of combined methods is known. To such methods, for instance, pertain: electro-chemical-mechanical treatment, anodic and mechanical with imposition of ultrasonic oscillations and electroerosion with imposition of ultrasonic oscillations, etc.

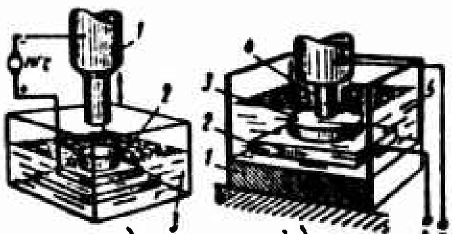

Fig. 23. Combined methods: (a) fundamental diagram of combined ultrasonic and electropluse treatment: 1 – electrode-tool; 2 – part; 3 – working medium; (b) fundamental diagram of combined ultrasonic and anode machining: 1 – insulating plate; 2 – table; 3 – part; 4 – electrode-tool; 5 – working medium.

Combined methods, as a rule, differ in effectiveness as compared to the separate methods entering in them.

In Fig. 23a is represented the diagram of combination of electropulse treatment with

ultrasonic vibration of electrode tool 1 which facilitates removal of waste and increases productivity of process. In Fig. 23b is shown a combination of anode machining with ultrasonic vibration of electrode tool, also leading to increase in treatment rate.

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CHAPTER VI

TECHNOLOGY OF APPLYING COATINGS ON MACHINE PART

GALVANIC COATINGS (ELECTROPLATING)

Types and designation of galvanic coatings. Coating, accomplished in galvanizing shops, are divided into the following basic groups.

Protective coatings: zinc, cadmium, lead, tin and nickel: alloy coatings: cadmium-zinc, tin-zinc, copper-zinc, lead-tin, zinc-nickel, and also protective films, obtained by means of phoshating, oxidizing, etc.

Protective decorative coatings: copper with subsequent additional finishing (oxidizing and so forth), nickel, chromium, cobalt, silver, gold, rhodium, and also coating with alloys; copper-tin, tin-nickel, nickel-cobalt, gold-copper, etc.

Coatings for increasing resistance to mechanical wear and surface hardness: chromium, iron, nickel.

Coatings for restoration of part dimensions: chromium (sizing chromium plating, and with subsequent finishing), iron and copper.

Coatings of metals for special purposes.

The basic types of coatings have following designations [11], [13], [19].

Zinc coating is used for protection of machine parts, fasteners,

from corrosion steel sheet, wire and other parts which work in different climatic conditions, in closed locations with moderate humidity, in locations contaminated by gases and combustion products, in the atmosphere, contaminated by sulfur gas, and also for protection of water lines which supply reservoirs and similar parts in contact with fresh water at a temperature below 70°.

Cadmium coating is used for protection from errosion of items and machine parts in contact with sea water and solutions containing chlorides (with the exception of acids), and also for packing of threaded connections and for ease of screwing.

Electrolytic tin coating is used for protection from corrosion of equipment of the food industry, contacts, piston rings, and also for local protection of steel parts from nitration (during partial nitriding). Contact tin coating is applied for the purpose of improving the operation of aluminum pistons.

Lead coating serves for protection from corrosion caused by the influence of sulfuric acid, sulfur gases and other sulfurous and sulfate compounds.

Copper coating is applied as a sublayer under nickel, chromium and other coatings during protective-decorative treatment of steel parts, for local protection of steel parts from carburization, for manufacture of bimetals prior to oxidizing the surface, for improvement of friction surfaces, and also for protection of contacts and chemical equipment from corrosion (fractionating columns, etc.)

Nickel plating without a sublayer is used for protection from corrosion of chemical and electrochemical equipment used with alkali solutions, medical instruments, friction parts for the purpose of increasing surface hardness and resistance to mechanical wear, and as a sublayer before copper plating of steel in an acid electrolyte.

Nickel plating of steel with a copper sublayer or copper and its alloys without a sublayer is used for protective and decorative finishing of surfaces, and also as an anticorrosive coating of clamp contacts of electrosetting parts for connecting them to copper and aluminum wires.

Chromium plating steel without a sublayer of copper and nickel serves to increase surface hardness and resistance to mechanical wear, for restoration of part dimensions, and also for protection of friction surfaces from corrosion. Chromium plating with a sublayer of copper and nickel is used for protective and decorative finishing and increasing reflectability of surfaces. Porous chromium plating serves to improve operational performance and to increase resistant to mechanical wear of piston rings and cylinders.

Silver plating is used for protection from corrosion of parts in contact with alkali solutions (chemical equipment), for increasing reflectability of headlight and searchlight reflectors, and also to increase the conducting properties of contact surfaces, for protective and decorative finishing of parts of wide consumption, etc.

Covering with gold is used for protection from corrosion of different laboratory equipment, for instance, calorimetric bombs, small weights of analytical scales and others, for decorative finishing of jewelry, watch and clock parts, different adornments, artistic and historical monuments and others.

Rhodium coating improves reflectance of surfaces, increases surface hardness and resistance to wear of friction parts.

Coating with indium increases corrosion resistance and prevents mechanical damages (dents, scratches, local wear) to the surfaces of antifriction alloys. As an antifriction coating indium is also used in the form of alloy with lead (3-4% In) and copper (~8% In).

Coating with iron ("steeling") increases resistance to mechanical wear of friction parts and is used to increase the life of printing forms in the printing industry, restoration of worn out parts of machines, apparatuses and so forth (bringing them to normal dimensions), and sometimes as the sublayer on cast iron parts before subsequent coating with tin or zinc.

Oxide coatings (oxidation of metals) are used for protection of metallic articles from corrosion and for decorative finishing of them.

Oxide films on steel, copper and its alloys protect surfaces from corrosion in closed areas with a nonaggressive, corrosive atmosphere; giving them a beautiful appearance with a different color, chiefly, black.

Oxide films on aluminum and its alloys serve as a basic means of protection of these metals from corrosion in different atmospheric conditions, and also are used as a primer under varnish and paint coatings and as a pigment in the decorative finishing of surfaces, for increasing surface hardness and resistance to mechanical wear, for insulating surfaces.

Phosphatizing with subsequent anticorrosive treatment (chromate solutions, oiling, varnishing, etc) is used for protection of steel parts from corrosion in the open atmosphere and in closed areas, for improvement of surface cohesion of varnish and paint films, and also for applying an electric insulating layer of transformers, rotors and stator plates, used in the electrical industry.

Phosphatizing zinc parts with subsequent treatment in a solution of potassium bichromate increases corrosion stability of zinc coatings.

Sulfidizing of cast iron and steel parts is used for improvement of friction wear surface lubrication (valves, pushers, piston rings and others) and prevention of burring, jamming, welding ("freezing").

Coating with a copper-zinc alloy containing 60-65% Cu (brass plating) is used for corrosion protection and decorative finishing of various parts with subsequent oxidizing, and also as a substrate before electrolytic nickel plating, chromium plating, silvering, and tinning of steel parts. Copper-zinc alloy coatings (70% ~ Cu) are widely used to increase bonding strength between steel and rubber during hot pressing with subsequent vulcanization.

Coating with a copper-tin alloy (bronzing) with a varying content of tin (8-40% Sn) is used for corrosion protection and decorative finishing of surfaces. Coating with a low-tin alloy (Sn 8-20%) also serves as the substrate in exchange for copper and nickel prior to chromium plating. A high-tin alloy (40-45% Sn), called white bronze, has white color and can be used instead of silver. This coating can be easily polished and brazed and in contrast to silver does not lose its luster under the action of sulfur compounds.

Coating with a tin-nickel alloy (50-65% Sn) is used for protective and decorative finishing of surfaces instead of nickel plating, chromium plating and in certain cases instead of tinning for increased requirements of mechanical properties of a coating (hardness, resistance to wear, polishing ease). Decorative chromium plating of steel with a copper and nickel substrate can be replaced by coating with a tin-nickel alloy with a single copper substrate without an intermediate nickel plating.

Coating with a lead-tin alloy, containing from 10 to 60% Sn, has received much use in industry for protection of steel from corrosion, especially when soldering is necessary and also for imparting antifriction properties. For ease of soldering, with these alloys (30-60% Sn), they coat there parts in the small wire industry. As

an antifriction coating, for increasing reliability of engine bearing, an alloy containing 92-88% Pb and 8-12% Sn, is used.

Coating with a tin-zinc, containing 75-80% Sn, is used in the radio engineering and electrical industry for corrosion protection of steel parts operating in the atmosphere at increased humidity and variable temperature. This alloy can be easily brazed, resists action of low temperatures and is not subject to being eaten up — transformation of white compact tin to friable gray tin.

Coating with a cadmium-zinc alloy serves for corrosion protection of steel parts working in an atmosphere contaminated with chlorides, or under conditions of direct contact with sea water, and also for corrosion protection of threaded parts instead of cadmium plating. The greatest stability against corrosion is possessed by an alloy containing 80-[illegible] Cd and 20-17% Zn.

Coating with a zinc-nickel alloy containing 10-18% nickel may be used for corrosion protection of steel parts, working in an atmosphere with variable humidity and temperature. This coating is significantly more stable to corrosion than a pure zinc coating, and ensures anode protection of steel parts.

Nickel-cobalt coating is used for protective and decorative finishing of surfaces, increasing surface hardness and mechanical wear resistance and, as a substrate before chromium plating, silvering, and gilding. A coating of this alloy, even at a small cobalt content (1-4%), has shiny surface and does not require polishing. Recently, nickel-cobalt coating (62-85% Co) has been used for magnetic recording of sound and other signals instead of powder sound carriers.

A gold-copper coating containing 10-20% Cu is used in the timepiece and jewelry industry instead of gold for the purpose of economy for increasing hardness.

Table 1. Minimum Thickness Coating Layer

Coatings	Minimum thickness of coating in microns					Operating conditions for parts
	Single layer			Multilayers of Cu-Ni or Ni-Cu-Ni on steel		
	zinc or cadmium	Nickel without substrate		Total thickness	Thickness of top nickel layer	
		on steel	on copper and copper alloys			
L (light)	5	10	3	10	5	Parts working in an atmosphere of closed, dry, heated and ventilated locations
M (medium)	15	30	6	30	10	Parts working in closed locations and in an external atmosphere contaminated with industrial gas and dust, and also containing the evaporation of sea water. Parts not subjected to the direct action of rain and snow
R (rigid)	30	–	10	45	15	Parts operating in an atmosphere contaminated with a significant quantity of industrial gases and dust, and subjected to the direct action of rain, snow and sea water

<u>Remarks</u>: 1. On complex shaped sections of parts, fasteners and small parts, and also springs a decrease of coating thickness less than the norms of corresponding groups of coatings is permissible so that each separate case is established by corresponding standards, intraplant norms or technical specifications on parts depending upon sizes and shapes of parts and conditions of their operation.

2. For parts working for a short time, and also in hermetically sealed equipment in the absence of moisture condensation a coating can be applied with a thickness smaller than the norms of group L which in each separate case is established by corresponding standards or technical conditions.

3. Requirements for protective coverings of parts of special designation are stipulated by technical conditions.

4. The average thickness of a chromium coating for all groups is taken to be 0.5 microns.

Table 2. Average (Calculated) Thicknesses of Single-Layer Metal Coatings

Designation of coating and conditions of part functioning	Types of coatings	Thickness of covering microns*
Protection from atmospheric corrosion:		
light conditions	Zn,Cd	7-10
average conditions	Zn,Cd,Zn-Cd,Zn-Ni	17-22
severe conditions	The same	35-40
Protection from corrosion and decorative finishing:		
light conditions	Ni,Cu**,Cu-Zn** Cu-Sn	13-18
average	The same	30-35
Protection (local) from:		
carburizing	Cu	20-30
nitriding	Sn	10-20
Increase of resistance to wear and surface hardness:		
measuring tool	Cr	5-25
cutting tool	Cr	3-8
other parts	Ni or Fe Cr	10-100*** 5-100***
Protection from corrosion, caused by liquid media:		
tap water up to 70°	Zn	50
sea water and similar solutions . . .	Cd,Pb-Sn	40-50
alkali solutions	Ni	50-200***
dilute solutions of sulfuric acid and its salts, sulfite and sulfide compounds	Pb	50-200***
Corrosion protection in canned foods . . .	Sn	1-2
Protection from corrosion of dairy products, boilers and other parts used in the food industry	Sn	10-25

Table 2 (Continued)

Designation of coating and conditions of part functioning	Types of coatings	Thickness of coverings in microns*
Protection from corrosion, and also for providing antifriction properties to part surfaces	Pb-Sn	30-60
Giving surfaces lubricating properties .	Cu	5-15
Increasing electrical conductivity . . .	Ag Sn	5-15 10
Coating of brass or steel copper-plated clamp contacts of electrical equipment .	Ni	see Table 1

*For protection from atmospheric corrosion and for protective and decorative treatment the lower limit of coating thicknesses is shown for flat parts, and the top limit for relief parts.

**Coating with copper or brass before oxidizing.

***Thickness of coating is designated per character of parts, conditions and duration of operation.

Table 3. Average (Calculating) Thickness of Multilayer Coatings

Designation of coating and conditions parts functioning	Thickness of coatings in microns						
	Cu (cyanide electrolyte)	Cu (acid electrolyte)	Ni	Cr	Ag	Au	Total
Protective and decorative treatment:							
light conditions	8	-	10	1	-	-	19
	3	30	-	-	5-7	-	38-40
	3	30	-	-	-	1-3	34-36
average conditions . . .	3	22	15	1	-	-	41
	3	40	-	-	10-15	-	53-58
	3	40	-	-	-	5-7	48-50
	23	-	15	1	-	-	39*
severe conditions . . .	35	-	20	1	-	-	56*
	3	37	20	1	-	-	61
	3	47	-	-	20-30	-	70-80
	3	47	-	-	-	20-30	70-80
Protection from corrosion caused by alkali solutions	-	-	20	-	10-100**	-	30-120

Note: 1. Substrates of copper from cyanide solutions may be replaced with brass of the same thickness.

2. For parts of simple configuration the first copper substrate from cyanide electrolytes may be replaced by nickel of the same thickness.

3. For copper plating of part of very complex shape only coatings in cyanide electrolytes are used.

4. In bright nickel plating without subsequent polishing, thickness of nickel coating should be 2-4 microns less than indicated.

5. Thickness of tin-nickel coating replaced by nickel and chromium coatings should be the same as in nickel plating.

*For a zinc alloy coating.

** Thickness of silver in the indicated limits is selected with respect to alkali concentration.

Table 4. Requirements for Surface of Parts Set Forth for Plating Shops

Coating designation	Type of coating	Requirements for part surfaces
Protection from corrosion:	Zn, Cd Pb, Sn	Deep nicks, cracks, large pores, scale, inclusions, projecting edges, laminations, burrs are not allowed on surface**
Protection from corrosion and decorative finishing:		Parts of a zinc alloy, before coating, should not have slag inclusions, gas and shrinkage cavities on surface
multilayer coating	Cu+Ni+Cr	
single layer coating	Cu,* Ni, Cu-Zn (brass)*	
Local protection:		
from carburizing	Cu	Surface of parts with permissible partial, point carburization must be cleaned by turning; parts surfaces, hot to carburized, must be polished
from nitriding	Sn	Surfaces have to be turned and polished
Increase of resistance to wear and surface hardness:		
tools	Cr	Surfaces must be polished to size
other parts	Cr, Ni, Fe	Surfaces must be polished
piston rings, cylinders (porous chromium plating)	Cr	Surfaces of piston rings have to be turned, surfaces of cylinders—ground and polished
Giving surface lubricating properties	Cu	Surfaces have to be ground
Increasing electrical conductivity	Ag, Sn, Ni	No deep nicks, pores, deeply fixed scale cinder, inclusions, and projecting edges are allowed on surfaces

*Coating with copper and brass before oxidizing.

**For details with exact tolerances and pitch, one should consider coating tolerance.

Joint deposition of gold with other metals: copper, nickel, silver, is also done to give the coating a specific color.

The thickness of galvanic coatings [13], [19], [20], [26], [35], is selected in reference to conditions of part operation (Table 1).

Duration of the coating process is determined, proceeding from the average thicknesses of metal coatings (the value of which in reference to steel parts are given in Tables 2 and 3). For cast iron parts with a porous surface the thickness of the first layer increases by approximately 50%. For nonferrous metals thicknesses of coatings of other metals (nickel, chromium and others) can be taken as for copper-plated steels. Requirements for part surfaces in plating shops are given in Table 4.

Technological process of applying galvanic coatings [19], [26], [35]. The technological process of applying coatings consists of surface preparations before coating, applying coating and treatment of surface after coating.

Surface preparation of parts before coating is done by mechanical, chemical and electrochemical methods. Mechanical preparation is divided into the following: grinding, polishing, sand or shot blasting, etc. To the chemical and electrochemical forms of treatment belong: degreasing), pickling in acids or alkalis, anode removal of pickling slime, passivation or activation, and washing.

Surface preparations before coating and a diagram of all technological processes depend on surface condition of coated parts and on the type or designation of coating. Items coated, for protection from corrosion, with zinc, cadmium, lead and others, are degreased, pickled or rough machined, for instance sand or shot blasting, and passivated or activated. Parts coated with copper, nickel, chromium, silver, gold and their alloys for the purpose of protective and decorative

finishing of surfaces, increasing hardness and resistance to wear, improving reflective properties, etc., are subjected, furthermore, to careful mechanical treatment — grinding and polishing on lathes, miller machines and other apparatuses with subsequent chemical and electrochemical treatment: degreasing, pickling, etc.

After applying coatings they are washed, dried and, in the case of protective and decorative or other special finishing, sometimes are subjected to polishing. Parts, coated with zinc, cadmium or subjected to phosphatizing, oxidizing, are processed, furthermore, in passivating solutions to increase the anticorrosive stability of the coatings.

Compositions of solutions and operating mode for different operations of the technological process are given in Tables 5-7.

Selection and characteristics of equipment [19], [21], [26]. In large scale and mass production of coated parts automatic machines are used. The best models are automatic machines with program control.

Automatic machines with program control are used mainly for coating large parts (bumpers, handrails of busses, etc.) and parts coated by additional anodes or by a chemical method. The automatic machine consists of consecutively fixed (rectilinear) baths, above which the control system is situated on a special frame. All movements of the system (raising suspension system, transfer from the bath and to bath and lowering) are executed by a definite cyclogram on the basis of a given technological process. With the automatic machine several types of coatings or one coating with a different process time can be produced simultaneously which is its greatest advantage over other automatic units. A drawback of this automatic machine is its limited productivity, since it works with a low output per 7-10 minutes. At higher rates installation of a second control mechanism is required

which complicates operation.

Table 5. Compositions of Solutions and Operating Conditions of Baths for Chemical and Electrochemical Surface Preparation [2], [3], [6], [7], [19], [22], [23], [26], [33]

No. of solutions	Composition of solutions in g/l	Operating conditions			Designation
		Temperature in °C	Current density in a/dm^2	Time in min	
	Degreasing				
1	Gasoline, kerosene	18-25	–	5-10	For all metals
2	Trichloroethylene	87	–	5-10	For steel, zinc, copper and their alloys
3	Caustic soda 10, trisodium phosphate or liquid glass 15-30, OP-7 or OP-10 1-3, antifoam PMS-200(polymethylsiloxane liquid) 0.5-1.5. Solution continuously stirred	50-70	–	5-20	For removal of oils, lubricants and polishing paste from the surface steel and nonferrous metals
4	Ditto for jet treatment (pressure 2-3 atm)	70-80	–	1-3	Ditto
5	Caustic soda 30, sodium carbonate or sodium phosphate 30-50, OP-7 or OP-10, 1-3	70-80	3-10	1-5	For ferrous metals, copper and its alloys
6	Trisodium phosphate ~50, liquid glass 3-5	60-80	3-10	1-3	For zinc alloys
7	Caustic soda 10, sodium carbonate sodium or trisodium phosphate 30	60-80	~5	5 on cathode 1 on anode	For nickel
	Simultaneous degreasing and pickling				
1	Sulfuric acid 150-200 OP-7 or OP-10 3-5, antifoam PMS-200 (polymethylsiloxane liquid) 0.5-1.5 or white alcohol 20 ml/l, (pressure 1.5-2.5 atm)	45-60	–	3-5	For ferrous metals
2	Phosphoric acid 200-300, OP-7 or OP-10 2-3, PMS-200 0.1-0.5 or white alcohol 20 ml/l	60-70	–	3-5	For ferrous metals parts and assemblies

Table 5 (Continued)

No. of solutions	Composition of solutions in g/l	Operating conditions: Temperature in $^{\circ}C$	Current density a/dm^2	Time in min	Designation
	Pickling				
1	Sulfuric acid (Sp. gr 1.84) 150-250 or hydrochloric acid (Sp. gr. 1.19) 100-150, inhibitor (MN, KS and others) 3-10	20-50	–	10-40	For carbon steels
2	Sulfuric acid (Sp. gr. 1.84) 50-100, hydrochloric acid (Sp. gr. 1.19) 100-150 inhibitor (MN, KS and others) 3-10	20-50	–	10-40	Ditto
3	Ditto, but without inhibitor during jet treatment	20-25	–	2-5	Ditto
4	Sulfuric acid (Sp. gr. 1.84) 10-20, iron sulfate 200-300, Sodium chloride 30-50	18-25	5-10 on anode	3-10	Ditto
5	Sulfuric acid (Sp. gr. 1.84) 100-150	20-60	–	10-30	For removal of scale from copper
6	Nitric acid (Sp. gr. 1.4) ~1000, hydrochloric acid (Sp. gr. 1.19) ~5	18-25	–	0.5-1	For preliminary pickling of copper and its alloys
7	Sulfuric acid (Sp. gr. 1.84) 1000, hydrochloric acid (Sp. gr. 1.19) ~3, nitric acid (Sp. gr. 1.4) ~750	18-25	–	0.1-0.3	For glossy pickling of copper and its alloys
8	Caustic alkali (NaOH or KOH) 50-100, sodium chloride 30 . .	60	–	No. 1	For aluminum and its alloys
	Passivation (activation)				
1	Sulfuric acid (Sp. gr. 1.84) 50-100	15-25	–	0.5-2	For steel, copper and its alloys
2	Sulfuric acid (Sp. gr. 1.84) 700-850	15-25	5-10 on anode	No. 1	For steel
3	Potassium cyanide or sodium cyanide 30-40, potassium sodium carbonate 20-30	15-25	3-5	0.5-1	For copper and its alloy
4	Chromium anhydride 150-250 sulfuric acid (Sp. gr. 1.84) 1.5-2.5	45-50	5-10 on anode	0.5-1	For steel before chromium plating
5	Hydrochloric acid (Sp. gr. 1.19) 200	18-25	–	~5	For nickel after electrodegreasing in solution No. 7

Table 6. Compositions of Solutions and Operating Conditions for Coating Baths [4], [8]-[20], [24]-[33], [35], [36]

No. of solutions	Composition of solution	Current output in %	Operating Conditions: Temperature in °C	Operating Conditions: Current density in a/dm^2*	Designation
	Galvanizing				
1	Zinc sulfate 215-300, aluminum sulfate 30[or $KAl(SO_4)_2$ $12H_2O$ 60 g/l], Sodium sulfate 50-150, dextrin 10, pH = 3.8-4.4	98-100	18-25	$\frac{1-2}{3-5}$	For different parts
2	Zinc sulfate 430-500, aluminum sulfate 30, pH = 3.8-4.4	98-100	18-25	$\frac{2-3}{3-10}$	For sheets, plates, etc.
3	Zinc sulfate 575-715, aluminum sulfate 30	98-100	40-50	$\frac{-}{30-400}$	For wire and strip on a conveyor installation
4	Zinc oxide 12-15 (or zinc sulfate 42-52 g/l), ammonium chloride 240-260, boric acid 20-25, carpenters glue 1-2, pH = 6.5-6.8	96-100	30-35**	0.5-1.5	For parts of complicated shape
5	Zinc oxide 40-45, sodium cyanide 80-85, sodium hydroxide 80-85	80-85	18-25	2-3	For parts of complicated shape
6	Zinc oxide 40-45, sodium cyanide 80-85, sodium hydroxide 70-85, glycerine 3-5, sodium sulfate 0.5-5 .	80-85	18-25	2-5	The same during bright galvanizing
7	Zinc oxide 5-10, sodium cyanide 20-30, sodium hydroxide 25-50, tin (in the form of a stannate) 0.3-0.5	50-60	20-40	0.5-2.0	For parts of very complex shape
8	Zinc oxide 4-6, sodium hydroxide 60-70, tin (stannate) 0.5-1.0	96-99	50	$\frac{\text{To } 0.7}{1.4-1.7}$	The same
9	Zinc oxide 10-12, sodium hydroxide 70-90, tin (stannate) 0.5-1	96-99	50	$\frac{\text{To } 1.5}{2-2.5}$	For parts of complex shape
	Cadmium plating				
1	Cadmium sulfate 100, boric acid 20, sodium chloride 30, glue 5, pH = 2.5-4.5	95-98	20	$\frac{\text{To } 1.2}{5}$	For sheet and simple parts
2	Cadmium fluoboride 140, fluoboric acid 35, glue 1 . .	95-98	20 50	$\frac{\text{To } 4}{\text{To } 10}$	The same
3	Cadmium oxide 45, sodium cyanide 120, sodium sulfate 50, nickel sulfate 1-1.5 . .	85-95	20 40	To 1-2 To 4	For parts of complex shape
4	Cadmium oxide 30, ammonium sulfate 250, boric acid 20, thiourea 5, dextrin 10; pH = 6.8	95-100	20-25	0.5-1	The same

*The numerator gives current density without mixing, and denominator — with mixing.

**In jars at 18-20°.

Table 6 (Continued)

No. of solutions	Composition of solution	Current output in %	Operating Conditions: Temperature in °C	Operating Conditions: Current density in a/dm²	Designation
	Tinning				
1	Tin sulfate 50-55, sulfuric acid 100, cresol or 20-30, glue 2-3.	95-100	20-40	$\frac{\text{To } 1\text{-}2}{5}$	For parts of simple shape
2	Tin chloride 75, fluoride sodium 25, ammonium fluoride 50, disulfonapthalenic acid 2-3, ammonium thiocyanate 1-2	95-100	60-70	To 30	For tinning of strip
3	Potassium stannate 90-115, potassium hydroxide 10-20 .	70-80	70-90	To 10	The same
4	Sodium stannate 50-100, sodium hydroxide 8-15, sodium acetate 20-30 . . .	60-70	65-75	0.5-2	For parts of complex shape
5	Sodium stannate 8-25, sodium hydroxide 8-12 . .	60-70	65-75	0.5-0.7	For parts of very complex form
6	Tin chloride 30, sodium hydroxide 20 (time 3-5 min).	—	70-75	—	For tinning of aluminum pistons
	Lead plating				
1	Lead fluoboride 180-200, fluoboric acid 40-45, carpenter's glue 0.5-1.0 . . .	95-100	20-25	$\frac{0.5\text{-}2}{\text{To } 5}$	For different parts
2	Lead salt of paraphenolsulfonate 140-200, paraphenolsulfonate 20-40, carpenter's glue 0.5-1 . .	95-100	20-50	$\frac{0.5\text{-}2}{\text{To } 5}$	The same
	Copper plating				
1	Copper sulfate 200-250, sulfuric acid 50-75	100	18-25 45-50	$\frac{\text{To } 2}{\text{To } 4}$ $\frac{—}{4\text{-}8}$	For building up copper on a copper or nickel substrate by switching to the anode at a ratio $t_a:t_к \approx$ 1:10 sec
2	Cyanide copper 30-45, 45-65 cyanide sodium (including free cyanide 10-15), sodium carbonate 50-70 . .	60-80	18-40	0.5-1.5	For a steel and zinc alloy (at the smallest content of free cyanide)
3	Cyanide copper 60-70, sodium cyanide 80-95 (including free cyanide 12-15), potassium thiocyanate 13-18, sodium tartrate 6-13, sodium hydroxide 25-30, manganese sulfate 0.02-0.04	—	50-60	On cathode to 2-3, on anode to 4-5	For bright copper plating with periodic change of current direction at a ratio of 40 sec: 4 sec or 25 sec: 3 sec; vibration period of cathode rods 20-40 oscillations per 1 min

Table 6 (Continued)

No. of solutions	Composition of solution	Current output in %	Operating Conditions		Designation
			Temperature in °C	Current density in a/dm^2	
	Nickel plating				
1	Nickel sulfate 250-300, chloride nickel 60-80, boric acid 30-40, coumarin ~1, paratoluene-sulfamide ~2 "progress" 0.1; pH = = -4.5-5	90-95	45-55	— / 4-6	For bright nickel plating with smoothing or surface
2	Nickel sulfate 210-420, sodium (or potassium) chloride 5-15, boric acid 20-30 pH = 4.5-5.5	90-95	50	0.5-2 / To 4	For dull nickel plating
				— / To 10	For sheets and parts of simple shape
3	Nickel sulfate 140-300, sodium (or potassium) chloride 3-15, boric acid 30, potassium or sodium fluoride 5-6 naphthalene-sulfo acid (isomers 2.6 or 2.7) 2.4 (pH = 5.8-6.3)	90-95	25-45	0.2-1 / 1.5-5	For bright nickel plating
	Chromium plating				
1	Chromium anhydride 250, sulfuric acid 2.5	13-15	45-50	10-25	Decorative chromium plating
				35-75	"Hard" chromium plating
2	Chromium anhydride 250-400, strontium sulfate 5-7, potassium fluosilicate 20	15-18	50-70	40-100	Decorative chromium plating in self adjusting electrolyte
	Silvering				
1	Silver cyanide or nitrate 2-5, potassium cyanide 70-90	50	18-25	1-2	Preliminary silvering of copper and its alloys
2	Silver nitrate 45-50, potassium cyanide 50-60, potassium 40-50, potassium or sodium nitrate 50-100, carbon disulfide ~0.01	80-100	18-25	0.3-1	Raising of silver (after preliminary silvering)
	Gilding				
1	Gold (on metal) 2-8, potassium cyanide 15-20 .	60-80	60-80	0.1-0.3	—
	Iron plating				
1	Ferrous sulfate 420, potassium sulfate 150, oxalic acid 1, pH = 2.5 .	98-100	20	To 3/5	For obtaining deposit of iron
			40	To 8/12	
			70	To 12/15	

Table 6 (Continued)

No. of solutions	Composition of solution	Current output in %	Operating Conditions: Tempera-ture in °C	Operating Conditions: Current density in a/dm²	Designation
2	Ferrous chloride 600-750, hydrochloric acid to pH ~ 1	95-98	100-105	10-50	For obtaining soft deposits of iron
	Brass plating				
1	Copper cyanide 25, zinc cyanide 20, sodium cyanide (free) 15-20, sodium carbonate 30-40	60-80	60-70	0.5-1.5	For applying substrate on steel prior to coating with other metals 60% Cu + 40% Zn; $t_a:t_k$ = 1:10 sec
2	Copper cyanide ~15, zinc oxide 6-7, free sodium cyanide 10, ammonia (25% solution) 0.25-1.	60-80	20-30	0.3-0.5	For increasing cohesive strength between steel and ~70% Cu + + ~30% Zn alloy
	Bronzing				
1	Copper (in the form of a cyanide salt) 15-18, tin (in the form of a stannate) 23-28, sodium or potassium cyanide 26-30, sodium hydroxide 9-10	60-75	65-70	2-3	For protective and decorative finishing and as a substrate prior to nickel plating or chromium plating
2	Copper (in the form of a cyanide salt) 8-12, tin (in the form of a stannate) 40-45, sodium hydroxide 8-20, sodium or potassium cyanide 8-15 . .	65-70	60-65	1.5-3.0	For decorative purposes (to replace silver) — white bronze

Coatings with alloys — cadmium-zinc (Cd-Zn), tin-zinc (Sn-Zn), lead-tin (Pb-Sn), zinc-nickel (Zn-Ni), tin-nickel (Sn-Ni), nickel-cobalt (Ni-Co), gold-copper (Au-Cu), and others. See special literature [5], [14], [15], [19], [28], [32].

No. of solutions	Composition of solution g/l	Tempera-ture in °C	Current density in a/dm²	Time in min	Designation
	Oxidizing				
1	Sulfuric acid 200 (voltage 11-28 v depending upon composition of aluminum). .	15-23	0.8-3 on anode	20-50	For corrosion protection of aluminum and its alloys with subsequent anticorrosive treatment
2	Oxidation of steel with subsequent submersion in two baths:				
	1) sodium hydroxide 800-900, potassium nitrate 25-50, water 1 liter . .	140-145	—	5-10	For corrosion protection of steel parts with
	2) sodium hydroxide 1000-1100, potassium nitrate 50-100, water 1 liter. .	150-155	—	30-45	

Table 6 (Continued)

No. of solutions	Composition of solution g/l	Temperature in °C	Current density in a/dm²	Time in min	Designation
3	Sodium hydroxide 700-800, sodium nitrate 200-500, sodium nitrite 50-70. . .	138-145	–	20-120	subsequent anti-corrosive treatment
4	Sodium hydroxide 400, chromium anhydride 30	80	5-10 on anode	30-60	
5	Potassium dichromatic 30-50 potash alum 8-12, acetic acid (60% solution) 5-7 ml/l pH = 3.5	15-30	–	5-10	For corrosion protection of magnesium and its alloys
6	Potassium hydroxide 80-90 potassium fluoride 300 . .	45-50	3-4 on anode	8-15	
7	Sodium hydroxide 50-60; potassium persulfate 15. .	60-65	–	5	For copper and alloys with large content of copper
	Phosphatizing				
1	Preparation "Mazhef" 30-33; relationship of total acidity $K_{общ}$ to free $K_{св}$ equal to 7-10.	97-99	–	40-65	For corrosion protection of ferrous metals with subsequent anticorrosive treatment (Table 7)
2	Preparation "Mazhef" 60-65, zinc nitrate 50-100 fluoride sodium 4-6; zinc oxide 6-8; pH = 3.2-3.4.	20-30	–	30-40	
3	Zinc monophosphate $Zn(H_2PO_4)_2$ 70, sodium nitrate 35, sodium nitrite 1.2; total acidity 60 points, free acidity 2-2.5 points – during jet phosphatizing	25-30	–	3.5	
4	Orthophosphoric acid 20-30, zinc oxide 15-25, sodium nitrate 20-30, sodium nitrite 1.5-2; pH = = 2.4-2.8 (Sp. gr. 1.05-1.06)	28-32	–	30	For increasing corrosion stability of zinc coatings* with subsequent chromate treatment
	Ferrosulfidizing or sulfurizing				
1	Sulfurizing. Sodium sulfate 1.5, sodium bicarbonate (drinking soda) 2.3, hydrochloric acid 1 ml/l; pH ≈ 6.5 . .	Initial 30 Final 99	–	90	For prevention of burrs sticking, welding of cast iron and steel parts

NOTE: For electrolytic coatings in drums of jars current density, shown in the table, should be decreased 2-4 times.

*Before phosphating fresh-galvanized parts, dip in a solution, containing 1-4 g/l soap and 3-6 g/l sodium carbonate (soda) at t = 18-25° for 30-60 sec.

Table 7. Chemical Treatment of Coatings and other (Intermediate) Operations

No. of solutions	Process	Solution: Name	Content in g/l	Temperature in °C	Regime: Time in min
	Purification and improvement of anticorrosive surface properties				
1	Cleaning after galvanizing and cadmium plating	Chromium anhydride Sulfuric acid (Sp. gr. 1.84)	150 3-4	18-25	0.1-0.2
2	Cleaning after galvanizing of cyanide electrolytes containing sulfate sodium	1. Nitric acid (Sp. gr. 1.4). Washing in cold water	10-30	18-25	0.05-0.1
		2. Chromium anhydride. Washing in cold water	50	18-25	0.1-2
3	Anticorrosive treatment after galvanizing	Sodium dichromate Sulfuric acid (Sp. gr. 1.84)	150-200 10-20	18-20	0.1-0.2
4	The same after oxidizing aluminum and its alloys	Potassium dichromate Sodium carbonate (pH = 6-7)	100 18	90-95	2-4
5	The same after phosphatizing steel	Potassium dichromate	50-80	60-80	8-10
6	The same after phosphatizing zinc	Potassium or sodium dichromate	3	70-80	0.5-1
7	The same after oxidizing and phosphatizing steel	Spindle or machine oil	-	90-110	0.5-1
	Miscellany				
8	Cleaning aluminum alloys containing copper, before oxidizing	Nitric acid (30-50%) chromium anhydride Sulfuric acid (Sp. gr. 1.84)	100 6-10	18-25	0.2-0.5
9	Removal of hydrogen	Oil (spindle or machine)*	-	150-200	60-90
10	Neutralization after acid solutions	Sodium carbonate	30-50	15-25	0.5-2
11	Anode removal of pickling slime	Sodium hydroxide at anode current density of 5 a/dm^2	50-100	18-60	5-10
12	Removal of pickling slime with brushes	3%-solution of soda or lime slurry, chalk sand etc.	-	-	-
13	Amalgamation of copper and its alloys before silvering	Mercuric oxide Sodium cyanide	75 60	18-20	0.1-0.2

*Or desiccator

Table 8. Duration of Metal Deposition Depending upon Current Density (Thickness of Layer 10μ, Current Output-100%

Type of treatment	Time of treatment in min at current density in a/dm^2									
	0.1	0.2	0.3	0.5	1	2	3	5	10	20
Galvanizing	—	—	—	70	35	18	12	7	4	2
Cadmium plating	—	—	—	50	25	13	9	5	3	—
Lead plating	—	—	—	36	18	9	6	4	2	—
Tinning in acid electrolytes .	—	—	—	40	20	10	7	4	2	—
Tinning in alkali electrolytes	—	—	—	79	40	20	14	8	—	—
Copper plating in acid electrolytes	—	—	—	90	45	23	15	9	5	—
Copper plating in cyanide electrolytes	—	—	75	45	23	12	8	—	—	—
Nickel plating	—	—	—	97	49	25	17	10	5	—
Brass plating	252	126	84	50	25	—	—	—	—	—
Iron plating	452	226	151	92	46	23	15	9	5	3
Silvering	157	79	52	31	16	—	—	—	—	—
Gilding.	160	80	53	32	—	—	—	—	—	—
Chromium plating (Current output 13%)	—	—	—	—	—	—	—	200	100	50

Note: At a current output below 100% it is necessary to divide the time shown in the table, into the coefficient A/100, where A — output of metal in percent. In calculating coating time of small parts in drums and vats one should proceed from the average (calculated) current density. During deposition of metals, for other thicknesses, the time of electrolysis changes correspondingly.

An automatic machine with vertical levers is intended for coating parts of average dimensions. It consists of baths arranged in an oval. All moving parts of the automatic machine are located outside the baths which excludes the possibility of contamination of solutions by grease and dust. Levers for suspensions of parts are equipped with carts, which can move up and down with the help of hydraulic or pneumatic devices. Shift of control levers along the baths of the automatic machine is done with the help of two horizontally positioned chains put in motion by an electric motor. By means of a corresponding mechanism, individual levers with loads can pass to one bath or a group of baths. This makes it possible to carry out, in one automatic machine, several types of coatings, combining preparatory operations, or to operate in different processes. For the possibility of loading details under current the current conducting bars can be disposed vertically. Owing to the independent operation of mechanisms moving raising and lowering, the following additional measures for improvement of a technological process can be carried out:

a) oscillation of brackets while in the bath will make it possible to increase current density:

b) multiple raising and lowering of brackets in the wash bath will greatly improve washing quality of parts;

c) by means of an additional attachment a decrease in operating time (for instance, cleaning of zinc).

Automatic machines of this type will increase productivity.

Coating of small parts is done in bell automatic machines of varying productivity.

For coating wire and strip special automatic machines or conveyer belt installations are used which consist of three independent

assemblies: unwinding attachment, unit for coating (series of baths) and, attachment for winding wire and strip in coils after coating. During installation of automatic machines it is necessary to anticipate a system of continuous or periodic filtration of solutions, and also reserve capacities for over flow and correction of the latter.

Table 9. Materials, Recommended for Bath Linings [26]

No. of process	Type of Process	Character of solution	Lining material				
			Rubber	Polyisobutylene	Piece materials	Enamel	Vinyl plastic
1	Copper plating	Acid	+	+	+	-	+
2	Nickel plating	"	+	+	+	-	+
3	Galvanizing	"	+	+	+	-	+
4	Cadmium plating	"	+	+	+	-	+
5	Tinning.	"	+	+	+	-	+
6	Lead plating	"	+	+	-	-	+
7	Iron plating in cold electrolytes	"	+	+	+	+	+
8	Ditto in hot electrolytes. . . .	"	-	-	+	+	-
9	Silvering	Cyanide	+	-	-	+	-
10	Gilding	"	-	-	-	+	-
11	Oxidizing aluminum in sulfuric acid	Acid	+	+	+	+	+
12	Pickling steel at a temperature to 50°C	"	+	+	+	-	+
13	Pickling steel at a temperature higher than 50°C	"	-	-	+	-	-
14	Pickling of copper and its alloys	"	-	-	+	+	-
15	Chromium plating	"	-	-	+	-	-

Note: 1. To the inlaid materials belong acid-resistant brick, ceramic tile, diabase plate and others, which are used for the baths of processes 1, 2, 3, 4, 5, 11, and 12 — on mastic bituminol and, for baths of processes 8, 13 and 14 — on silicate putty, in both cases on a Ruberoid base. Bituminol and Ruberoid cannot be used at a solution temperature above 60°.

2. Baths of processes 9 and 14 can be prepared also from ceramics.

3. For chromium plating baths heated by steam it is necessary to use sheet lead.

In a small program of coating output, and also for preparatory and finishing operations, during treatment of parts on brackets, stationary baths of different sizes, prepared in most cases from welded sheet steel 4-6 mm thick, are used.

Depending upon the character of processes, stationary baths of automatic machines are equipped for steam, water, air, and electric heating, and also ventilated. Baths for acid solutions are internally (lined) with acid-resistant materials (Table 9).

For coating and surface preparation of small parts rotating vats and drums (hexagonal or round) of different sizes depending upon magnitude of load and dimensions of processed details, are used parts with cutting points and threads on the external surface — bolts, screws nuts and others — are processed chiefly in vats; flat parts — plate, discs, etc., and also hollow parts, partially engaged in one other — only in drums.

Consumption of anodes and materials. Consumption of anodes in grams is determined by the formula

$$G_a = FS_\gamma + \Delta G$$

where F — coated surface in cm^2; S — thickness of coating in cm; γ — specific gravity of metal; ΔG — loss of metal (during casting of anodes and drilling of holes at the expense of scrape during remelting, and at the expense of slime formation and so forth), taken for all metals, except silver and is gold, in a quantity of 5-8% weight of metal, required for coating; for silver and gold losses are not considered.

Consumption of soluble anodes in g/m^2 at thickness of coating per 1 micron is expressed in the following quantities:

Anode	Consumption (in g/m^2)
Zinc	7.67
Copper	9.61
Cadmium	9.33
Tin	7.86
Lead	12.27
Brass (40% Zn, 60% Cu)	8.72
Silver	10.5
Gold	19.3

Note: In consumption losses in the amount of 8% weight of coating of metal, except silver and gold are included.

Consumption of insoluble anodes (lead) for chromium plating and cathodes (lead) for oxidizing of aluminum depends on dimension of bath and surface of loaded parts. During chromium plating it is recommended to take ratio of anode surface to cathode as 1:2 to 2:3, during oxidizing of aluminum the ratio of cathode surface to anode, from 3:2 to 2:1.

Anodes, during chromium plating, must be changed 2 times a year.

Consumption of chemical and other materials. They determine consumption of materials for baths of electrolytic coatings with soluble anodes by proceeding from the total quantities solution losses during galvanizing processes mainly due to removal of solutions by parts [26], [34].

Calculation of consumption of materials in g/m^2 is done by means of multiplying the magnitudes of solution losses by the content of each component, in g/l, given for a technological process.

In cyanide electrolytes loss of cyanides as a result of their decomposition of air by carbon dioxide and acid vapors, anode oxidation of cyanides and so forth are considered also. Losses of cyanides during

decomposition can be taken per 1 amp-hr in baths for an electrolyte temperature 18-20°C – from 0.5 to 0.7 g, at 25-45°C – from 0.7 to 0.8 g, in baths at a temperature over 45°C, and also in vats and drums – 0.8-0.9 g.

For chromium plating baths, working with insoluble anodes, one should also consider consumption of chromium anhydride in the precipitation of metallic chromium on the cathode from a calculation of 13.3 g CrO_3 per 1 m^2 at chromium deposit thickness of 1 micron.

For consumption of materials in chemical methods of applying coatings and operations of chemical, electrochemical and mechanical surface preparation and finishing see [26], [34].

Consumption of materials in the oxidation of steel and copper (during work in 2 shifts) is determined from a calculation of fourfold exchange of solution per year.

<u>Methods of quality control of galvanic coatings</u> [1], [19]. An appraisal of the quality of coatings can be done: a) externally (inspection with the naked eye) on the basis of comparison with standards; b) by results of laboratory tests on the basis of requirements for coatings as set by GOST or technical conditions.

Protective and protective decorative galvanic coatings are tested for thickness, porosity, surface cohesion of basis and anticorrosive properties. Coatings, applied to increase resistance to mechanical wear and surface hardness, are tested also for hardness and wear resistance. In isolated cases they test coatings for reflectability, heat resistance, and other properties depending upon nature and use of coating.

Testing coatings <u>for thickness</u> is done by a chemical method, based on dissolution of coating (without destruction of base metal) from the entire surface or only from separate sections of it. In first case

average thickness is found, in the second – local thickness of coating.

In determining local thickness of a coating the section being tested is dissolved under the action of a stream of solution, flowing from the capillary hole of a tube at a definite speed (jet method stream), or by applying and holding for a definite interval of time, drops of the solution (drop method) until base metal is exposed.

The method of chemical thickness control is described for zinc, cadmium, copper, nickel and multilayer coatings in GOST 3003-58, for tin coverings – GOST 3263-46.

Pores in coating are revealed by means of filter paper, impregnated with reagents, giving colored compounds with ions of the base metal or metal the substrate underlayer. In sections of the coating, not covered with filter paper, pores are revealed by filling with a reagent which gives colored compounds with ions of base metal. A method of determining porosity is described for single-layer coatings of copper, nickel and chromium and multilayers from the same metals in GOST 3247-46, for tin – GOST 3264-46, for zinc – GOST 3265-46.

Cohesian of coating with base metal can be tested for sheet material by bending 90° or 180° to rupture of sample, for wire – coiling sample around rod of the same or large diameter depending upon diameter and use of wire, for parts – by scratching, a number of intersecting scratches with a steel blade by filing. In all cases there should be no cracks and foliation of coating.

Hardness galvanic coatings is tested by methods of scratching and damped oscillations of a pendulum. The first method consists in penetrating the coating with the use of a diamond or sapphire point under a definite load with subsequent measurement of width of indentations. In the second method they measure duration of pendulum damping

impinging on the coating surface. Obtained results are compared with standard tests of metal, the hardness of which is known.

For test of wear resistance of coatings, no laboratory methods exist.

Anticorrosion properties of coatings are determined by the method of accelerated tests in and artificially created corrosion media and according to the behavior of coated parts in natural conditions of their operation. Accelerated tests for corrosion stability of coatings are usually produced in fog chambers with a salt solution. Depending upon nature and use of the coatings, they are also tested in a saturated aggressive gas atmosphere or in a liquid medium, according to the composition of corresponding conditions of parts usage.

For metal coatings of an anode character, i.e., protecting parts electrochemically as for instance, zinc coatings, methods of accelerated testing are unsuitable.

METALLIZING BY SPRAYING

Essence of the method consists of melting of metal and its spraying by a stream of compressed air or other gas. Here the metallic particles formed (10-100 microns) at a high speed (100-150 m/sec) strike against the surface and is bonded with it, forming a metal coated layer.

At present the term "metallizing by spraying" has lost its literal meaning and frequently pertains to analogous processes of spraying coatings from nonmetallic materials: plastics, ceramics, metal oxides and other compounds.

Existing processes of applying coatings by spraying are executed by means of special equipment (Table 10), which classify either the state of the material use for spraying (wire, powder, rods, etc.), or the method of its fusion (gas apparatuses, electric arc, high-frequency,etc.)

Table 10. Equipment for Metallizing and Flame Spraying

Make of equipment	Use	Initial material for spraying	Method of fusing coating material	Distinctive peculiarities of design
		Powders		
UPN-1*	Applying coatings from plastics and other materials with melting points up to 500°C	Powders with particle sizes 0.15-0.25 mm	Air-acetylene flame	Unit consists of hand spray torch, powder feeder and panel with instruments for controlling process
UPN-4U*	Applying coatings from plastics and metals with melting points up to 1200°C	Ditto	Flame from mixture of acetylene with air or oxygen	Unit with spray torches for applying plastics (GLN-4) and metals (GTN-4). Supply of powder can be produced by a system of pressure, vacuum and mixed
UPN-5*	Spraying aluminum oxide	Powder of technical alumina (Grade G-0 and G-00)	Oxygen-acetylene flame	Installation consists of hand spray torch and powder bin. Atomization is produced by stream of flame without use of compressed air
IMYeT-105	Applying coatings from refractory materials	Finely dispersed powders	Plasma jet	Working gas is argon, nitrogen, hydrogen, helium or their mixtures. Spraying tip is equipped with a system of water cooling. Sources of power for arc are d-c generators
		II. Rod		
MGP-1*	Applying coatings from aluminum oxide and other refractory ceramic materials	Solid rods ϕ 3 mm, l = 400-500 or flexible pipe	Oxygen-acetylene flame	Consists of hand sprayer and electrical drive, equipped with a friction governor. Torch drive mechanism is drive via flexible shaft
		III. Wire, gas		
GIM-2*	For light forms of metallizing manually and on machines	Wire ϕ 1.5-2.0 mm	Flame from mixture of oxygen with combustible gas (acetylenc, propane, hydrogen and others)	Apparatus of the injector type. Supply of wire is done from a built-in air turbine, equipped centrifugal governor. Limit of adjustment 0.8-4.5 m/minutes. Weight-2.5 kg

Table 10. (Continued)

Make of equipment	Use	Initial material for spraying	Method of fusing coating material	Distinctive peculiarities of design
MGI-1*	Ditto	ϕ 1.5-3.0 mm	Ditto	Limit of adjustment 0.7-6.0 m/minutes. Weight-2 kg
MGP-2	For spraying molybdenum coatings and other refractory metals	Wire ϕ 3 mm	Oxygen-acetylene flame	Construction is analogous to MGP-1
IV. High-frequency wire				
MVCh-3	Machine tool apparatus for metallizing with steel	Wire ϕ 4-5 mm	Heating with high-frequency inductor	Block is a conical heating inductor fed by a vacuum tube oscillator with a frequency of 70,000-50,000 cps. Block and coaxial power cable are water cooled. Drive of feed mechanism is electrical. Speed control of feed is by means of gears
V. Electrical wire				
EM-3A*	For light forms of metallizing manually and on machines	Wire ϕ 1-2 mm.	Electrical arc excited between two wire electrodes	Construction of drive of feed mechanism is analogous to an apparatus of the GIM-2. For work of apparatus is required alternating or direct current (voltage, 20-30 v; current, 100-150 a)
EM-9*	Ditto	Wire ϕ 1.2-2.0 mm	Ditto	Ditto. Drive is analogous to apparatus MGI-1
EM-6*	Machine tool apparatus for metallizing of rotating bodies	Wire ϕ 1.5-2.0 mm	Ditto	Highly productive apparatus, working on a-c and also direct current. Drive of feed mechanism is from an electric motor equipped with governor
MES	Machine tool apparatus EM-6, equipped with elongated head for metallizing clanic pins	Ditto	Ditto	Ditto

Table 10. (Continued)

Make of equipment	Use	Initial material for spraying	Method of fusing coating material	Distinctive peculiarities of design
MTG-1*	Machine tool apparatus EM-6 with three-wire angle head for applying antifriction pseudoalloys on internal surfaces of bearing bushings etc.	Wire ϕ 1.0-1.5 mm	Electrical arc between three wire electrodes	Works on single-phase alternating current from a welding transformer. Allows to obtain two and three-component coatings from dissimilar metals in a given ratio. Useful for plating internal surfaces of bushings with diameters of 90 mm and larger
		VI. Plasma wire		
UMP	Installation of machine tool type for applying refractory metal coatings: Molybdenum, tungsten and others	Wire ϕ 1.0-1.5 mm	Plasma jet	Consists of highly productive (up to 8 kg of W per hour) spray apparatus and control panel. Works on direct current from converter PS-500. Spray tip is water-cooled
		VII. Suspension		
UPR-1	Unit for applying refractory metal and coatings	Suspension of powder in liquid fuel	Flame from mixture of propane-butane and oxygen	Consists of hand spray torch with a combustion chamber of rocket type, feeder and control panel

*Equipment, in series producted by industry.

The method of metallizing and similar processes are characterized by simplicity of equipment, simplicity of process and variety of regions for application.

Spraying plastics. For spraying both thermoplastics, and thermosetting resins are used and their composition is on the basis of powders with particle sizes of 0.1-0.25 mm.

The suitability of material for spraying is determined by their friability and capability to pass in the fused state without decomposition, and their adhesive ability.

Parts can be subjected to spraying if they can be heated to a temperature 50-100°C above the melting point of the coating material, and also if they have sufficiently open surfaces without acute angles, facets, gaps, cavities, etc.

Coatings are applied to a dry, clean surface, preheated to the flow temperature of the coated material. Thickness of coating covering layer is 0.3-0.5 mm., but in some cases it is possible to bring this value to 5 mm and above.

Plastics are sprayed chiefly on external surfaces, since liberation of a large quantity of heat makes work inside vessels practically impossible.

Gas-flame coatings from plastics are used for protection from corrosion and for the purpose of thermal insulation, electrical insulation, smoothing surfaces of parts (for instance, on bodies of automobiles) etc. For these purposes they use polyethylene, polypropylene polxvinyl butyral, polyamides, epoxies, thiokols, bitumens and other resins and different compositions of them. For spraying plastics the lot-produced industrial apparatuses UPN (Table 11) are used.

Table 11. Technical Specifications of UPN Units for Powder Coatings

Specification	UPN-1	UPN-4U with torch		UPN-5
		GLN-4	GTN-4	
Dimensions in mm.	490x490x1300	410x450x1120	410x450x1120	200x300x700
Total weight in kg	40	30	30	15
Weight of spray torch in kg . . .	1.1	1.2	1.4	1.2
Required pressure:				
compressed air in kg/cm^2. . . .	1.5-2.0	2-3	2-3	—
oxygen in kg/cm^2	—	—	3-3.5	5.5-6.0
acetylene in mm H_2O	Not below 50		Now below 200	400-500
Consumption:				
compressed air in m^3/min . . .	0.2-0.3	0.2-0.3	0.3-0.4	—
oxygen in m^3/hr	—	—	To 1.9	5.0-5.5
acetylene in m^3/hr	0.25-0.3	0.25-0.3	To 1.7	1.5-1.7
Capacity of feeder vessel in l .	8.5	3.5	3.5	5-6
Required size of crushed powder in mm	0.15-0.25	0.15-0.25	0.075-0.15	0.3-0.7

Metallizing. In spraying metals there occurs partial burn out of separate elements (C, Mn, Si, and others) and the formation on the surface of the particles of oxide films. Particles striking against a part undergo severe cooling and deformation, due to which the formed coating differs from initial metal both as in chemical composition and in physical properties. As to structure, metallized coatings are always porous and, therefore, their volume weight is 8-12% lower than that for cast metals.

During metallizing, melting or welding of particles with the surface does not occur and cohesion of coatings is purely an adhesion character. Most influence on cohesive strength of coatings depends on preparation of surface (Table 12).

Table 12. Influence of Surface Preparation on Bonding Strength of Metallized Coatings and Fatigue Strength of Parts During Cyclic

Method of Surface preparation	Fatigue limit		Bonding strength in kg/cm^2
	in kg/m^2	in % to polished surface	
Grinding	25.2	100	—
Sandblasting	27.8	110.5	345
Shot blasting	32.4	128.5	1040
Incision by chiseling . . .	20.6	82.0	820
Rolling (straight line, slanting, twisted)	30.6	121.0	1000
Triangular threading . . .	18.8	74.5	1800
Triangular threading with subsequent shotblasting . .	24.5	98.0	1900
Triangular threading with rolled crowns	17.0	67.5	1560
Round threading	19.4	77.0	1670
Round threading with rolled crowns	18.8	74.5	1440
Threading of annular groves	16.5	65.5	1400
Threading annular grooves with rolled crown	15.3	61.0	1130
Electrospark treatment . .	20.3	80.5	1000
Electric-arc treatment . .	17.0	67.5	250

Table 13. Mechanical Properties of Metallized Coating (VNIIAvtogen)

Metal	Ultimate tensile strength in kg/mm^2		Ultimate compressive strength in kg/mm^2		Hardness-HB	
	EM-3	GIM	EM-3	GIM	GM-3	GIM
Steel 15. . .	13.7	13.8	68.9	49.7	197	147
Steel 45. . .	14.1	15.5	64.2	73.0	240	240
Steel U8. . .	16.2	—	52.0	—	281	—
Brass L62 . . .	3.8	5.2	18.5	20.4	50	63
Aluminum A99.	5.4	5.0	14.2	13.1	27	26
Zinc Ts1 . . .	3.4	3.2	11.5	10.7	20	20
Copper M1. . .	8.2	5.4	28.4	32.0	66	64

Note: EM-3 and GIM — make of apparatuses, by which spraying was produced.

Mechanical strength of samples from atomized metal (separated from the base) is significantly lower than for cast metals (Table 13). Coatings also differ by a very low modulus of elasticity (for St. 3, $E = 700$ kg/mm^2), in connection with which stresses forming in the coating are always smaller than in the part. Owing to this metallized coatings work excellently under conditions of static loads, but only within limits of elastic deformations of the base.

Porous metallized coatings absorb up to 10% oil (by volume) which makes them very wear resistant and capable of longtime operation without lubricant and sticking. This property was the basis for obtaining special coatings from antifriction pseudoalloys, formed during simultaneous atomization of two or more different metals. These coatings, applied for the purpose of economy of nonferrous metals, as to their most important properties (Fig. 1) are suitable substitutes of babbit and

Table 14. Electrical resistance and coefficient of thermal expansion of metallized coatings

Metal	r μohm·cm	α 10^{-6}
Low-carbon steel . . .	40	12.0
Stainless steel . . .	243	15.0
Copper . . .	4.5	14.0
Brass . . .	13.5	17.5
Aluminum . .	10.0	24.0

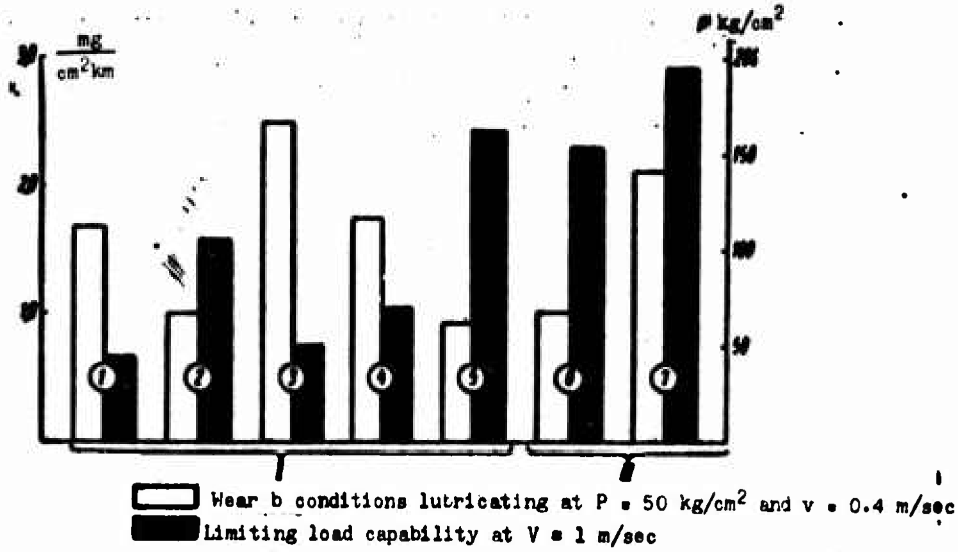


Fig. 1. Wear and load capacity of metallized coatings: I) metallized coatings; II) cast bronze; 1 — steel (100%); 2 — steel (50%) + + aluminum (50%); 3 — steel (75%) + brass (25%); 4 — steel (75%) + copper (25%); 5 — copper (75%) + POS 30 (25%); 6 — Br. OTsS 6-6-3; 7 — Br. OF 10-1.

bronzes. Under conditions of dry friction metallized coatings work unsatisfactorily.

The electrical conductivity of coatings in connection with their contamination by oxides in thin (to 0.1 mm) layers is lowered 8-10 times. Electrical resistance and coefficient of thermal expansion for thicker coatings are given in Table 14.

The technological process of metallizing is composed of operations of surface preparation (Table 15) for a metallic coating and its subsequent treatment. Losses of metal during electrometallizing can be determined by the diagram (Fig. 2) and Table 16.

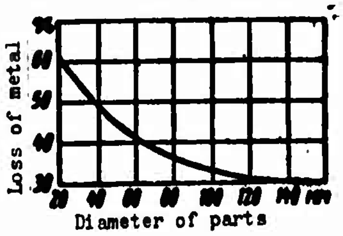


Fig. 2. Losses of metal during electrometallizing of external surfaces of rotating bodies in relation to their diameter.

Use of metallizing is as follows:

1. Corrosion protection of steel constructions, bridge girders masts, gas-holders, vessels, ships' hulls, etc. From atmospheric

Table 15. Basic Operations of Surface Preparation

Operation	Method	Application
Purification from grease and other contaminations	Hand wiping with rags, washing with solvents (kerosene, gasoline, dichlorethane and others), and treatment in washing machines	In all cases
Removal of oil (moisture) from metal pores	Heating with a torch or in a furnace to 250-300°C (to prevent visible liberation of volatile combustion products	During metallizing of part from cast iron and other porous metals, working under conditions of contract with oil and other liquids
Removal, from metal, of oxidized film and roughing surface of part to guarantee cohesion with applied coating	Sand blasting with dry coarse-grained, quartz sand with particle sizes of 1-2 mm. For small dimensions of parts manually sand blasting is in a cabinet at a pressure of compressed air of 4-6 atm	Chiefly, during preparation of flat surfaces and parts of complicated configuration, and also journals and cavities of intended for press fitting
Removal of irregularities ellipticity, burrs and obtaining required dimensions	Machining on lathe. It is possible to use one machine both for preparation of surface, and for metallizing	During metallizing of rotating parts
Roughing surfaces of rotating bodies to guarantee bonding with coatings	Threading on lathe-screw cutting machine of torn threads or treatment of surface by bundle of electrodes,	Part with hard surface (hardened, carburized, and others) can be metallized only during preparation for electrospark or electric vibration method

corrosion and action of water, steel parts are protected by coating with zinc, aluminum and cadmium. Subsequent impregnation of metallized coatings with polychlorovinyl, phenol, epoxy and other lacquers significantly increases their longevity.

Table 16. Losses of Metal During Electrometallizing of Planes Depending Upon Angle of Incidence of Jet

Angle in degrees	Loss of metal during atomization in %			
	Zinc	Aluminum	Brass	Steel
90	27.5	17.8	35.0	22.0
60	64.1	59.0	69.0	61.0
30	90.4	88.5	91.4	89.0
10	98.5	98.0	99.0	98.2

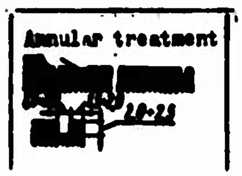
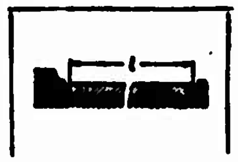
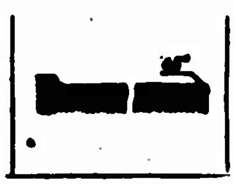
2. Restoration of worm out parts of equipment (journals, shafts, axles, pins, spindles, bushings, bearings and so forth), and also surfaces under pressure (bearing recesses bushings, and others). The sequence and method of fulfillment of operations during metallizing of journal are shown in Table 17.

3. Increasing hardness and wear resistance of parts by means of spraying them with coatings of hard alloys of "Stellite," and also chromium-boron-nickel self-fluxing alloys, the coating from which after application require thermal diffusion annealing these coatings besides a high hardness of HRC 40-60, possess high corrosion stability and stability to action of high temperatures.

4. Repair of dies and holds means of applying molybdenum coatings.

In connection with the volatility of molybdenum oxides its particles during spraying are welded to the part and form very durable and wear resistant coating, which allow to restore geometric dimensions of parts, subject to increased wear, for instance molds

Table 17. Sequence of Operations for Metallizing of External Surface of Journals

Type of operation	Sketch	Method
Turning of locking grooves ends of journal for output of cutter during subsequent operations. Leaving shoulders for protection of layer on the face part of journal from flaring and chipping		Notching without use liquid coolants
Machining of journal in length for removal of irregularities and guarantee of coating layer of minimum allowed thickness (0.70-1.0 mm per side)		Straight cutting without liquid coolants. At wear of journal from 1.5 mm in diameter and above no operation is done
Threading length of torn thread for giving to surface adequate roughness and guaranteeing proper bonding of coating		Threading with front angle $\gamma = 0^{\circ}$. Installation of cutter below center of part by 4-5 mm; distance 120-150 mm. Dry threading dry for one pass, at small cutting speeds. Removal of projecting edges
Application of metallized coating given diameter of journal		Angular speed of part is 20-60 rpm. Distance from tip of apparatus to surface of journal is 100-150 mm. Tolerance for treatment is 0.6-1.0 mm in machining and 0.4-0.6 mm in grinding (per side)
Machining and grinding of coating for obtaining required dimensions and surface purity		Machining with hard alloys with semicircular groove with radius of 3 mm. First passes at minimum depth of cutting. Machining and grinding during mandatory cooling with emulsions

dies, etc.

5. Correction of casting defects, for instance, removal of permeability of porous casting (turbine bodies pump parts motor blocks etc.), removal of leaks seam weld, and also plugging of casting and other cavities.

6. Increase of heat resistance of steel by means of aluminizing, consisting in applying on part an aluminum coating and its thermal diffusion annealing. Service life of parts from carbon steels and copper, working at temperatures of 850-900° (carburizing boxes, thermocouple jackets, crucible shells, and so forth), as a result of aluminizing is increased in 3-5 times and more.

7. Producing coatings for shielding in radio engineering, protection of parts from carburization during cementation, applying current-conducting coatings on plastics, ceramics and other materials, for manufacture of electric heaters, manufacture of dies and models, applying coatings from refractory metals (titanium, chromium, niobium, tungsten, molybdenum and others).

Coatings from refractory materials. Method of gas flame spraying allows to coat oxides of metals, carbides, silicides, borides and other compounds. An important merit of the method consists of the possibility, by simple means, to coat highly refractory materials low-melting ones without significant heating of the latter.

A practical application is coating aluminum oxide, zirconium dioxide, titanium dioxide, molybdenum disilicide, silicon carbide, certain cermets and others. Coatings from these materials are applied for protection of parts from the action of high temperatures, obtaining coatings stable to high temperatures (electrical insulating coating), and also coatings with a low heat-transfer coefficient, protection of surfaces from erosion destruction and so forth. By

means of such coverings to increase the period of service of parts of gas turbines, protect from oxidation nozzles and sockets of fuel injectors, protect housings of thermocouples, fasten transducers, working at high temperatures, etc.

Applying refractory coatings is done by means of specialized equipment, calculated for use spraying materials in the form: a) dry powders, b) suspension of powders in liquid fuel, c) flexible fibers consisting of powders, connected with burning during spraying of plastics, d) hard rods ϕ 3 mm.

Equipment. Auxiliary equipment required for metallizing is listed in Table 18.

In planning ventilation the rate of air movement in plane of the section of cabinets for metallizing should be not less than 1.0-1.2 m/sec, and for horizontal hood of machines — not less than 4 m/sec.

During work on electric arc and plasma apparatuses it is necessary to use goggles with dark-colored glass (type TIS).

When applying coatings inside vessels and in the absence of ventilation gasmasks, respirators or helmets-pressure suits, with compulsory supply of pure air (for instance MIOT-48 and MIOT-49 designs of NIOT VtsSPS) are used.

VARNISH AND PAINT COVERINGS

Types and use of varnish and paint coverings. Varnish and paint coverings (Table 19) are designed for surface protection of metal parts from corrosion, wooden — from moisture and rotting, and also for giving them, the required external appearance.

Table 18. Auxiliary Equipment for Metallizing Installation

Name and type	Designation	Remarks
General equipment		
Oil-water linear diffusor MVO-P*	Purification of air, passing from compressor section, from oil and moisture	At high atmospheric humidity additionally are established guard filters MVO-M*
Sandblasting cabinet*	Preparation of flat surfaces and parts of complicated configuration	Equipped with drawing ventilation
Sandblasting gun*	Purification with sand (with recycling of abrasive material)	Supplied with hoses with a diameter of 9.5 mm (GOST 71-55) and 19 mm (TU MKhP 397-A-29)
Cabinet for metallizing*	Fulfillment of all forms of work by manual metallizing	Equipped with drawing ventilation
Threading lathe of any type	Preparation of shafts bushings and other rotating bodies for metallizing and applying metallic coatings on them	Selection of machine is done in accordance with dimensions of parts
Telescopic exhaust hood*	Exhaust of metallic dust during machine metallizing	Established on support of machine and connected to drawing ventilation line
Equipment for electrometallizing		
Step down transformer type STE	Supplying electrometallizing apparatuses with alternating current	Welding transformers are used without a throttle. For the purpose of metallizing they have outputs 20-25-30-35 v
Welding motor generator type GSR-150, ZP-7.5/30 (with magnetic adapter), PSM 1000 and others	Supplying electrometallizing apparatuses with direct current	Used for increasing productivity of electrometallizing. Only generators with constant characteristics are suitable

Table 18. (Continued)

Name and type	Designation	Remarks
Switchboard with instruments	Turning on and turning off of metallizing equipment and control of operating conditions	Established close to working area
	Equipment for gas metallizing	
Bottles for compressed oxygen	Storage and transportation of oxygen	GOST 5313-54
Oxygen reduction valve	Lowering and adjustment of oxygen pressure	Any type
Bottle for combustible gas (acetylene, methane, oil, gas and others)	Feeding of apparatus by fuel gas	Instead of bottles it is possible to use welding acetylene generators (for instance GVR-3 and others) installed outside the working location
Reduction valve for combustible gas	Lowering and adjustment of pressure of fuel gases in bottles	Type of reduction valve is selected in accordance with gas used
Rotameter	Measurement of consumption	Type RS-3 and RS-5
	Miscellaneous equipment	
Stand for holding wire coils*	Unwinding of coils during metallizing	–
Holder	Fastening of hand metallizing apparatuses on support of machine	–
Hoses, tools and others	–	–
Metal sieve	Screening of plastic and metallic powders	–

*Prepared per model drawings of VNIIAvtogen.

Table 19. The Most Commonly Used Types of Varnish and Paint Coating and Their Use

Type of coating and its use	Requirement for coating surface	Example system of coating	The most commonly used varnish and paint materials	Example areas of use
		Atmosphere coating		
Single layer. Protection from corrosion	Special requirements as to color and appearance are not presented	Paint (Primer) in one layer	Oil paints and enamels, asphalt varnishes, nitroglyptals and others	Hidden surfaces of parts (bottom of frames of railroad cars). Frames and motors of automobiles hardware parts. Parts in period of interoperational preservation (roof sheets of freight cars). Simplest agricultural machines (harrow, rolls, plow-shares and others. GOST 5282-57)
Simple without finishing, protection from corrosion	Color sometimes designated, special requirements for appearance not presented, but small blotches, bittiness and similar defects are allowed	Primer and paint in one layer	Oil paints, enamels and varnishes, perchlorovinyl enamels and others	Internal surfaces of parts, not subjected to mechanical or direct atmospheric attack (agricultural machinery and motor vehicle construction), breaking devices railroad cars. Simplest road machines
Protection from corrosion and giving a decorative appearance	Color is designated; some uneveness is allowed mechanical durability	Phosphatizing.* Priming, local spackling and paint in two layers (for nitroenamels, up to three layers)	Oil paints and enamels, perchlorovinyl and synthetic enamels, nitroenamel and others	Boiler equipment, road machines, freight cars, trucks, tractors (external surface). Small parts of wide consumption
Normal degree of finishing. Protection from corrosion and giving a decorative appearance	Color is designated; smooth surface mandatory; brightness is not obligatory; mechanical durability	Priming, local and continuous spackling in one-two layers and paint in two layers (for nitroenamels, up to three layers)	Enamel with cold and hot drying (glyptals, perchlorovinyl and nitroenamel; carbamide or melamine formaldehyde enamels and others)	Compressors, motors, machines. Plane surfaces of wooden assemblies, agricultural machines (GOST 5282-57), parts from precision machinery

*In automobile construction (cabin, empennage) and agricultural machine building (sheathing of grain combines).

Table 19. (Continued)

Type of coating and its use	Requirement for coating surface	Example system of coating	The most commonly used varnish and paint materials	Example areas of use
High degree of finishing. Protection from corrosion and giving a decorative appearance	Color is designated; ideally-even, brilliant surface; high mechanical durability	Phosphatizing,* priming, local and continuous spackling in one-two layers,* clear paint, smoothing, paint in 2 layers (for autonitroenamels up to 4-5 layers); phosphatizing, paint in two layers with enamel	Synthetic hot drying autoenamels, pentaphthalic and nitroenamel and others; various synthetic hot drying enamels. Reflecting enamels	Bodies of automobiles, streetcars, passenger railroad cars; bicycles, motor cycles, sewing machines, refrigerators, washing machines, typewriters, instruments, etc.
Special finishings. Decorative for creating on part of a given figure (grid, crystals, etc.)	Color, figure, degree of evenness and brightness are designated	Priming, spackling,** paint, coating with special lacquers and enamels	Crystal varnishes, cracking varnishes, varnish "Moroz," enamel "Muar." Hammer enamels (on primer and without it)	Parts of precision machinery, boxes of radio equipment, typewriters, computing apparatuses
Imitational for imitation of texture of expensive breeds of tree	Figure is designated; ideally even surface. Mirror brightness	Priming spackling,** paint, applying figure, lacquering in three-five layers	Nitrolacquers	Parts of passenger automobiles and passenger railroad cars. Radio receivers
Fibrous for creation of rough surface	Form of material (paper, textile, asbestos fibers; crust, leather dust and others). Luster and color of coating are designated	Priming, painting, applying fiber or powder, paint in case of need	Synthetic hot drying enamels. Reflex enamels	Various instruments, small parts of wide consumption
		Special coatings		
Acid resistant	Color and appearance are indifferent	Painting and lacquering in several layers (up to 15); sometimes on a phosphatized and primed surface	Special enamels and varnsihes on the base of vinyl, epoxy and other synthetic resins	Machine parts and apparatuses, in contact with solutions of acids of various concentration

*In automobile construction (body, empennage).

**Depending upon quality of painted surface and presented requirements for surface of coating. Thickness of each spackled layer is 0.3-0.5 mm.

Table 19. (Continued)

Type of coating and its use	Requirement for coating surface	Example system of coating	The most commonly used varnish and paint materials	Example areas of use
Acid resistant	Color and appearance can be given	Priming, painting (up to 4 layers), sometimes lacquering (up to 7 layers)	Perchlorovinyl enamels and varnishes, acid-resistant varnishes and enamels. Epoxy enamel	Equipment, operating in an atmosphere of increased humidity with aggressive gases H_2S, CO_2, SO_4 and others
Alkali stable	Color and appearance make no difference. Sometimes can be given	Priming, painting or lacquering (up to 4 layers)	Epoxy varnishes and alkali stable enamels. Perchlorovinyl enamels	Equipment, in contact with alkalis of various concentration process of operation
Benzine resistant: during constant action	The same	Cleaning in tumbling apparatus, phosphatizing or passivation, painting or lacquering up to 4 layers, sometimes on primed or surface	Special primers and enamels of the type UB, VL-5.5 and varnishes with aluminum powder	Internal surfaces of gasoline tanks, flasks, canisters, etc. (instead of tinning and galvanizing); internal surfaces of pipes for transportation of oil;
during periodic contact with oil products	Color, appearance, degree of finishing can be given	Priming, spackling (in case of need), painting in several layers (up to 5)	Autonitroenamels, aluminum nitroglyptals, epoxy nitrocellulose enamels	parts, requiring decorative gasoline resistant coating for instance, motors
Oil resistant: during constant action	Color and appearance make no difference sometimes can be given	Color or lacquering, sometimes on primed or phosphatized surface	Bakelite varnishes, enamel of the type UB, nitroenamels, aluminum varnishes and others	Oil baths and reservoirs, parts of oil filters, etc. directly in contact with oils, internal surface of machines, crankcases of motors, etc.
during periodic action	The same	phosphatizing, priming, painting (for nitroenamels up to 4 layers)	Pentaphthalic, glyptal nitro- and nitroglyptal enamels and others	machines, automobiles, trolley busses and simple equipment and parts in contact periodically with oil and requiring paints with different degree of finishing

Table 19. (Continued)

Type of coating and its use	Requirement for coating surface	Example system of coating	The most commonly used varnish and paint materials	Example areas of use
Water resistant: running water	Color and appearance make no difference	Painting in 2-3 layer	Bakelite varnishes with aluminum powder, epoxy enamels	Water line equipment (internal surfaces);
still water	The same	The same	bituminous varnishes with aluminum powder, lead in natural drying oil	internal surfaces of tanks and reservoirs; surface of machines in contact with fresh water
Moisture proof	Color and appearance can be given	Phosphatizing, priming and painting in 2-3 layers	Epoxy, phenolformaldehyde and perchlorovinyl enamels	Instruments and equipment, working in conditions of increased humidity
Electric insulating*	Color, smoothness of surface and luster are given	Painting (lacquering up to 2-5 layers)	Insulating varnishes, special varnishes and enamels, nitroglyptals	Internal surfaces of electrical machines, windings of electrical machines, etc.
Current-conducting**	—	Priming (painting) sometimes on surface, subjected to sandblast treatment	Current-conducting primers and enamels of the type PS, 4BG (with addition of zinc dust, etc.)	For corrosion protection of weld seams
Luminescent	—	Lacquering, applying luminescent compositions	Dammar varnish with addition of luminescent substances	Scales, inscriptions, pointers and other luminescent indicators
Light absorbing	—	Painting in 2-3 layers (sometimes on primer)	Perchlorovinyl enamel of type KhS-77, alkyd enamel of type 1519	Internal surfaces of optical instruments, where maximum absorption of light beams is required

*For obtaining quality electrical insulation coating strict observance of regimes of drying of varnish and paint materials is required.

**Possess good electrical conductivity, permit welding on dried and damp primer, insignificantly burns during welding and prevent formation of scale in weld zone.

Table 19. (Continued)

Type of coating and its use	Requirement for coating surface	Example system of coating	The most commonly used varnish and paint materials	Example areas of use
Heat resistant*				
60-110°C	Color and appearance can be given	Painting (priming) or lacquering in 2 layers	Butyric or bituminous-oil varnishes, agricultural enamels and others	Various equipment, unreliable machine parts
200-250°C	The same	The same	Epoxy varnishes and enamels, silicoorganic enamels	Electrical machines and apparatuses, separate parts subjected to heating
350-400°C	Not given (usually color is silvery)	The same	Heat-resistant enamels of type AL-70 or AL-701, butyric-resinous varnishes of type KF-95 and GF-95, bituminous varnishes with aluminum powder	Turbines, boiler equipment, etc., automobile radiators, air heaters of exhaust hoods compressor parts, etc.
To 550°C	The same	Painting in 1-2 layers (better on sandblasted or phosphatized surface)	Heat resistant enamel (on varnish type FG-9) or No. 254 with aluminum powder	The same
Fireproof. Protection of tree from burning	Color and appearance usually not given	Paint in 1-2 layers or impregnation	Special impregnations, plasters and paints, perchlorovinyl enamels. Special antimony paints type S3 and S5	Wooden constructions

*Primer is applied during poor bonding with painted part, spackling not allowed.

**Precise selection of grades of varnish and paint materials is done for every concrete case per GOST, OST and TU in varnish and paint production. Oil varnishes, paints and enamels more recently being replaced by materials on a synthetic base. [no indication of location in original text. Tr. Ed. note]

Table 20. Approximate Stability of the Most Widely Used Varnish and Paint Coating with Respect to Various Corrosive Factors

Corrosive factors	Varnish and Paint Material							
	Bituminous	Oil	Glyptal modified, hot drying pentaphthalic enamels	Phenolformaldehyde modified	Vinyl	Melamine and carbamine formaldehyde	Nitrocellulose	Silcoorganic	Epoxy
Atmospheric conditions of average latitudes	Poor*	Satisfactory	Very good	Very good	Very good	Satisfactory	Good	Good	Very good
Tropical climate	"	Poor	Good	The same	The same	Poor	Satisfactory	"	The same
Water: fresh	Good	Satisfactory	Satisfactory	Good	"	Satisfactory	The same	"	"
sea	Satisfactory	Poor	The same	Satisfactory	Good	Poor	"	Satisfactory	Good
Mineral oil	Poor	"	Good	Good	Very good	Satisfactory	Very good	"	"
Gasoline	"	"	Satisfactory	"	The same	Good	Good	Good	Very good
Acids	Satisfactory	"	The same***	"	"	Satisfactory	Satisfactory	Satisfactory	Good
Alkalis	Poor	"	Poor	"	Satisfactory	The same	The same	Low	Very good
Prolonged heating in ^{o}C	60-100 To 400**	60-100	60-100	–	To 80	–	To 80	To 300 To 500	200-250

Note: In the selection of varnish and paint materials one should consider in addition to their protective properties, conformity to requirements, presented as to appearance of coating (color, lusture, figure) and quality of finish (ability to be ground and polished), allowed temperature of heating part (for application of artificial drying of coating), toxicity and inflammability of material, and also production of equipment for applying and drying varnish and paint coatings.

*Give increased atmospheric susceptibility during hot drying at 120-200°C.

**With heat-resisting fillers (aluminum powder and so forth).

***For pentaphthalic-poor.

Stability of varnish and paint coating (Table 20) depends on conditions of operation, ability of selected varnish and paint material to resist external mechanical or chemical aggressive effects, bonding (adhesion) at coating with painted surface, number of coatings layers and temperature of their drying, which is established depending upon the properties of varnish and paint materials, and also quality of technological process of applying coating. Stability of coating is increased in applying it on a rough or chemically prepared (anodized, phosphatized and so forth) surface. During putting, stability of coating is lowered.

A type of coating, character of finishing surfaces, use for this purpose are varnish and paint materials and, in case of need, indications of special types of surface preparation (casing with sand, soldering, phosphatizing and so forth) are used in technical conditions in manufacture of a part, and also in the drawings. In drawings, furthermore, there are indicated special requirements for coating, caused by design of parts or conditions of its assembly, for instance: "to ground in parts," "to paint before assembly inacessible areas," "to paint the areas of part connects," and so forth.

Requirements, presented for a painted surface. On surface of a part do not paint:

a) cavities, cracks, slag inclusions, uncleaned welded seams (welded parts);

b) dents, nicks, projecting edges, ripples and other surface defects (stamped parts);

c) Sandcrust, uncleaned projecting edges after trimming, casting shrinkhole (cast parts);

d) crack, burrs, knotholes (wooden parts) and so forth.

For removal of roughness on stamped and welded parts for high-quality painting they sometimes used soldering of the surface with a quick solder of special composition with subsequent filing and grinding.

For cast parts it is allowed, if this does not lower mechanical durability of part, to plug cavities and other defects of epoxy spackling with subsequent stripping by an abrasive material.

The degree of surface smoothing and necessity of removal of these or other defects is established in each individual case depending upon required degree of finish.

Technological process of applying varnish and paint coatings. The process of applying varnish and paint coatings forms from following stages: a) surface preparation; b) applying working mixture*; c) drying varnish and paint layers; d) treatment of coating (grinding, polishing and so forth); e) decorative finishing of painted surface (if necessary).

Surface preparation (Table 21) conists of removal scale, rust, oils, residues of salts, alkalis and acids, old paint, separated resins and nap (for wooden articles) and various mechanical contaminations, preventing good bonding with varnish and paint layer. In responsible cases, for development of anticorrosive stability and increase bonding of varnish and paint layer with coating, metallic parts are subjected to special chemical preparation (phosphatizing, oxidizing and so forth).

*Paint and varnish materials (primer, spackle, paint), added as dilution solvent or as diluents to the required viscosity.

Table 21. Methods of Surface Preparation for Metal Parts

Method	Operation	Use	Equipment and tools	Area of application
Purification from scale and rust				
Chemical	Etching with solution of sulfuric or hydrochloric acid, washing with water neutralization with solution of soda or lime* Etching with solution of phosphoric acid (composition No. 1120 TU MKhP-271-51), washing with hot water; neutratization (composition No. 107 TU MkhP 274-41)**	Removal of scale and large patches of rust. Removal of small patches of rust and residues of mineral oils; creation of surface with increased adhesion	Bath for pickling, washing and neutralization. Washing area with drains, covered with metal plates; hair or grass brushes; hose for water	Steel parts of small and average dimensions; part from sheet metal large and average parts from sheet steel
Mechanical	Pounding manually with pneumatic tool;	Removal of thick layers of scale and rust	Pneumatic hammer; blunted chisels; gear blocks	Large metal construction (boilers, bridges, cranes and so forth)
	Purification with sand cast-iron or steel shot Φ 0.5-1 mm, manually or automatically***	Removal of scale, rust and other contaminations; creation of roughness for increased adhesion	Shot blasting chamber or drum, shot chamber,**** hydraulic sandblasting installation,*****	Parts of small and average dimensions not requiring preservation of accuracy of dimensions (castings, forgings, faced parts)
	Mechanical and hand purification	Removal cinder, small patches of rust and other contaminations	Pneumatic or electric tool; wire brushes; scrapers, emery paper	Casting, rolled parts, weld seams, parts from sheet steel
	Mechanical or hand grinding	Removal of large patches of rust and scale	Pneumatic or electric with grinding wheel	Parts of large and average dimensions of simple configuration (body of all-metal railroad cars and so forth)

*Is allowed when impossible to use another method, since residues of alkalis and traces of acids, remaining after washing, and also unwashed insoluble salts, destroy varnish and paint coatings. This is replaced by treatment in solutions of phosphoric acid.

**At present, sometimes instead of this operation, they use phosphatizing primers or accelerated phosphatizing (in mass production)

***Creates high active surface, fast corroding in air; interval of time between purification and applying coating should be reduced to minimum.

****Treatment in shotblasting chamber to avoid deformation of part is permissible for metal not less than 3 mm thick

*****For avoiding corrosion, after purification, immediate washing of part (passivation) in a solution of sodium nitrite is required.

Table 21. (Continued)

Method	Operation	Use	Equipment and tools	Area of application
Thermal	Heating with acetylene-oxygen flame, manually purification*	Removal of scale by means of destruction	Special torch (fire brush), wire brush	Large metal constructions (bridges, cranes and so forth) and parts with thickness not less than 5 mm
		Purification from oils and dirt		
Treatment with alkaline solutions and organic solvents	Mechanical washing with white alcohol, gasoline, dichloroethane, trichloroethylene, etc.	Removal of oils and fats (dissolution)	Special washing units; washing tanks for jet washing	Metallic parts of average and small dimensions
	Hand washing with white alcohol, gasoline, turpentine**	The same	Hair brushes, rags	Various metallic parts
	Washing in hot alkaline solutions, washing in hot water, drying	Removal of oils and fats (by emulsifying) and other contaminations	Multitanic washing machine; baths	Metallic parts of average and small dimensions in mass and large-scale production
	Washing in stream of boiling wash or alkaline solution, ejected under pressure of 2.5 atm and higher	Removal of oils, fats and mechanical contaminations by means of emulsifying and mechanical action of jet	Boiler for heating, special atomizing nozzle, pumps for supply of liquid and dosage of chemical additive	Large parts, for instance cranes, excavators, metal construction and so forth
		Removal of old paint		
Chemical	Washing in white alcohol, turpentine, acetone and so forth, applying special compositions of washing with subsequent rubbing***	Removal of old paint by means of dissolution of reversible film (asphaltic varnishes, nitrovarnishes and so forth)	Ventilation unit for exhausting vapors of solvents, spatula for scraping	Various metallic parts
	Washing in 10-20% solution of caustic alkali at a temperature 80-90°C or applying alkali pastes, washing in water	The same, by means of chemical destruction of film	Bath, hair brush, spatula for scraping	The same

*Painting is done not later than 2 hr after purification and is better on warm metal.

**Does not ensure full removal of grease. Impairs sanitary conditions of work.

***For removal of varnish from wooden surfaces they use the composition: ammonia 25% 15, turpentine 85. Prescriptions of composition are given in %.

Table 21. (Continued)

Method	Operation	Use	Equipment and tools	Area of application
Mechanical	Purification by sand, steel shot or sand, scraping by hand tool	The same, by means of mechanical destruction of film	Shot-and sandblasting apparatus; scrapers, chisels, abrasive tool	Parts of small and average dimensions from sheet steel
Thermal	Burning in flame, scraping manually, grinding, rubbing with white alcohol	The same, by means of burning film	Soldering lamp with special torch, spatula, abrasive toot	The same
		Special treatment		
	Phosphatizing in solutions of manganese or zinc dihydrophosphate or zinc — in baths*	Creation of porous phosphate film, increasing corrosion stability and adhesion of surface	Bathes	Parts of small and average dimensions from sheet steel
	Accelerated phosphatizing by spraying or dipping*	The same	Special units	The same of average and large dimensions
	Chemical and anode oxidizing*	The same	Bathes	Parts from aluminum and its alloys and magnesium alloys
	Treatment in chromate solutions*	The same	The same	Parts from zinc alloys
	Passivation for protection from corrosion of purified surface**	Treatment in solution of phosphoric acid or sodium nitrite (for preserving up to 10 days)	Preheated bath	Steel parts of small and average dimensions

*For greater detail see section "Metal coatings."

**Simpler and less labor consuming than protection by lubricants. Selection of composition of passivating solution is done in every separate case depending upon grade of metal of processed part.

Priming of surface is done on a pre-cleaned and prepared surface. Priming layer should ensure durable bonding of surface with subsequent layer of coating. It should possess anticorrosive properties, moisture proofness, elasticity and simultaneously high mechanical strength.

Priming of parts from nonferrous metals and aluminum is carried out after chemical treatment of their surface for creation of oxide film, ensuring best bonding and increased anticorrosive stability of coating.

Spackling (lubrication) serves for smoothing surface; the number of spackled layers is determined by quality of surface and required degree of finishing of surface of coating and should be minimum, since the spackled layer lowers durability of coating. For special coatings in direct contact with an aggressive medium spackling is not allowed.

After drying the spackled layer and its grinding sometimes a clear paint is applied by which straightening is produced (correction of shallow roughness and defects by a greased mass).

Grinding of a dried spackled surface serves to smooth roughness, formed in process spackling, and is done manually or (during treatment of large surfaces of simple configuration) with a mechanized tool.

Grinding with water or white alcohol gives a more even surface, accelerates operation and decreases dust formation.

A paint is applied on a prepared surface in one or several layers. Painted layers have to be by nonporous, elastic and ensure good cohesion with preceding layers of paint coatings.

Finishing a painted surface consists of varnishing, polishing and decorative shaping.

Varnishing serves to give the paint coating increased protective properties, and also mirror brightness of surface of part; a varnish

coating is applied on a painted surface in one or several layers. Parts, painted with commerical enamels, are varnished only for special requirements.

Polishing is designed for developing specially an even and brilliant (mirror) surface by means of treatment with abrasive pastes and compositions manually or with a mechanized tool with application of felt and cloth disks, "tsigeyskoy" sandpaper and so forth.

Polishing of wood is attained by means of applying on its ground surface a thin transparent layer of varnish (with mirror brightness)

Decorative shaping (Table 22) is designed for final finishing of part and applying paint.

Table 22. The Most Commonly Used Types of Decorative Finishing

Type of finishing	Method of applying	Remarks
Engine turning (lineation)	Narrow decorative lines applied with brush from long squirrel hair or special machine; produced by oil and nitroengine turning paints	Decorative finishing of automobiles, bicycles, railroad cars and other parts
Decalcomania	Typographical diagram, carried out with oil paints on paper with special glue sub-layer, cover with oil varnish and, after drying to stickiness put varnish layer on part, tightly rubbing painted surface by hand or sponge then wash paper, wash off varnish residues with solvent and secure figure with transparent varnish	Application of stamp factory markings, inscriptions and other figures
Filling pattern with hand scription with a brush or without it	Figures applied by means of pattern by brush or atomization; for applying poly-chromatic figures apply a combination of several patterns. Sometimes they apply silk patterns on which required figure is applied by photographic means	Application of in-scriptions, figures, factory markings and so forth

Methods of applying working mixtures. For obtaining a quality varnish and paint coating a working mixture is applied on a dry surface or earlier applied and dried layer of varnish and paint material

in thin and equal layers; application of thick layer leads to formation bumps and roughness, which, during nonuniform drying, form wrinkles and cracks.

Certain varnish and paint materials (for instance, perchlorovinyl enamels) allow painting a layer on an undried layer of primer which reduces periods of drying and simultaneously increases cohesion of primer and paint layers.

Working mixtures are applied manually, mechanically and automatically (Table 23).

Drying of varnish and paint coverings. Distinguished by natural and artificial drying.

Natural drying is used very primarily for quick-drying varnish and paint materials (nitroenamels, perchlorovinyl enamels and so forth) the process of drying of which consists of basically in evaporation of volatilizing solvents. For removal of harmful vapors of solvents painted articles are placed in exhaust hood; the amount of exhausted air should correspond to intensity of evaporation of solvent. For large dimensions of painted articles and the impossibility to localize exhaust their removal is done with by overall flow-exhaust ventilation which should ensure permissible hygienic concentrations of vapors of solvents in working locations. The majority of industrial varnish and paint material require significant time for drying under natural conditions; therefore application of natural or artificial drying depends on the size of an industrial program and dimensions of articles.

Artificial drying is produced with heated air (convective), radiant energy (thermoradiation) and current of high or industrial frequency (induction).

Table 23. Methods of Applying Working Mixtures

Method	Characteristics	Equipment and tools	Remarks
Painting in semi-automatic and automatic machines	Highly productive. Accomplished atomization, dipping, rolling and so forth, sometimes is combined with operation of drying	Automatic machines and semi-automatic machines of various design	Simple painting of monotype articles in mass and large-scale production
Paint in drums and bells	Highly productive, automatically done. Allows combination of operations of painting and drying. Nitroenamels will be atomized usually through tip	Bell, drums with preheating or without it	Simple painting at small monotype parts (normal), small articles of wide demand
Paint with roller	Diagram from stereotype is transferred by tip on part and is secured by several layers of transparent nitrolacquer. Allows full automation	Set of stereotype, gelatinous shafts, equipment for atomization, chamber for painting and drying. Compressed air at pressure 3-6 atm	Imitation of valuable breeds of trees in automobile and railroad car construction. Used for parts of simple configuration
Paint in electrical field of high voltage with use of air, electromechanical or electrostatic atomization of paint*	Highly productive, produced automatically on conveyer.** Electrically charged atomized particles of paint are deposited on primed article. Reduces expenditure of varnish and paint material by 30-50%. Gives good quality of covering***	Installation for creating electrical field (voltage 85,000-140,000 v), current intensity up to 10 ma). Spray devices; pneumatic atomizers with remote control: cup, disks and so forth, rotating motor of direct current or pneumatic turbine	Painting small, average and large parts and assemblies without deep recesses and housings (painting of internal surfaces is impossible)
Dipping or submersion	Highly productive. Produced automatically on conveyers or manually for small volumes of production; in work with paint mixtures does not give fast deposition of pigments; permits use of preheated paint mixtures which allows to reduce number of applied layers	Bath for paint, device for filtration, mixing (circulation) and pumping; for large baths-special-lacquer preserving with mixed devices around workshop. Baths with water jackets for preheating paint to 40-60°C	Simple painting of parts of streamlined form without "pockets" and "cavities" (painting assemblies of complicated configuration without blotches and running is impossible)

*Electric field of high voltage allows also to remove thickenings and running of paint after dip painting. Time of operation is from several seconds to 1 minute.

**Or special manual atomizer, working at a voltage of 90,000 v and current strength of 0.2 amp. Power of installation ~ 100 watts.

***For painting in an electric field for the purpose of obtaining the biggest economy it is recommended to combine with thermoradiation drying "of black radiation."

Table 23. (Continued)

Method	Characteristics	Equipment and tools	Remarks
Jet painting with subsequent holding of painted articles for runoff of paint in vapors of solvents of high concentration ("Flow-Coating" method")	Highly productive. Executed automatically. Gives less porous and more uniform covering than in ordinary painting by drenching or dipping. Improves appearance of covering by decreasing blotches and running. Lowers expenditure of paint as compared to dipping by 20%, and to atomization — by 30-40%. Ensures high stability of technological modes of paint due to automatic control	Installation, consisting of drenching chamber with system of nozzles for supply of paint, tunnel for runoff of surplus of paint and drying chamber (in most cases — thermoradiation type). System for preheating and supply of paint. Installation for recovery of solvents. Automatic control of temperature, concentration of vapors of solvents, viscosity of paint and so forth. Automatic carbon dioxide installation for quenching fires	Painting of articles of different configuration and dimensions with presence of in accessible areas. Used instead of painting by atomization, dipping and usual drenching in conditions of mass production in various branches of machine building
Air spraying	Universal and productive (up to 200 m^2/hr) method. Gives thin, even covering (11-20 microns). Applied manually and automatically removal of paint fog and vapors of solvents requires application of powerful ventilation equipment. Permits use of preheated paint mixtures which reduces number of applied layers of covering	Stationary or mobile (for large articles) painting chamber; for high-quality paint — chamber with down draft and air conditioning; equipment for atomization. Compressed air at pressure of 3-6 atm*)	Painting various parts of large and average dimensions; painting small parts (stampings) on sus-pensions
Spraying without air with preheating (airless method) or without it (method Hydraspray)	Highly productive (350 m^2/hr and higher); fog formation is insignificant and application of powerful ventilation unnecessary. Atomization with preheating gives small particles, without preheating — large	Exhaust chamber for catching vapors of solvents; special aggregate with atomizer and hoses. Electric heater. Pressure of pump during painting with preheatings is 20-40 atm, without preheating — to 200 atm	Painting large parts of simple configuration (vessels, cargo railroad cars, platforms of cargo motor vehicles, bridges and so forth)
Brush painting	Universal, but of low productivity (10-20 m^2/hr); for a high-quality finish it is necessary to use a blowpipe [?] to remove the brush marks	Brush painter (OST 90073-40, 90074-40). Brush wheel (OST 90072-40) for painting large surfaces	Painting different articles chiefly in small-scale and unit production.

*Atomizers for synthetic enamels, working at pressures of 1.7-2 atm have been developed.

Drying with heated air of all forms of varnish and paint materials is carried out in drying chambers, heated by steam to 60-120°C, gas or electricity to 160-220°C.

The most used are vapor drying chambers with battery air heating (with additionally fixed heating instruments inside chambers) and compulsory circulation of hot air for more intense heating of parts. In convective drying the influence of hot air is subjected only to surface of covering, on which will form a hard film delaying drying of the lower layers of paint and volatilization of solvent vapors from them.

Drying by radiant energy (thermoradiation) is based on rapid heating of metal of painted article by infrared radiation of heated body (special electric heaters; panels, heated by gas; coils electric lamps and so forth), freely passing through layers of covering. Drying of covering goes from internal layers to external which improves its quality and accelerates process of drying.

For drying by radiant energy there are used: reflector (lamp) dried and dried "black radiation" with radiators in the form of panels, tubular heating elements and ceramic heaters of different form, heated by gas (burner inside panels or in outlying furnace) or by electricity to 400-450°C. As compared to reflector dried, "black radiation" give more uniform heating, is more simple and economic to use, and reduces time of drying by 15-20%. The most economic is "dark radiation" with circulation of heat air to 120-130°C, useful for drying of last layer of covering and for articles of complicated configuration. They are often supplied with devices for automatic control of temperature. Reflectors (lamps) are chiefly used for local drying of painted surface and made in the form of sliding panels.

Recently such panels have been placed by mobile thermoradiators with electric heating.

<u>Drying with high-frequency</u> current is used for uniform steel articles in conditions of mass production. Articles dry on a conveyer, moving inside special solenoids (inductors), in which passes current with a frequency 250-800 cps. The temperature of heating article is 200-300°C ensures intense drying of varnish and paint film. Drying by vhf current has not received wide application due to nonuniform drying of film on articles of complicated configuration.

<u>Drying with current of industrial frequency</u> of painted articles of large dimensions (railroad cars) is done with the help of mobile solenoids, ensuring heating of surface to 100-280°C. Drying with hf current is used for metal with thickness not less than 2 mm and reduces time as compared to a reflector by several times. Approximate power consumption is 0.7-1.0 kilowatt/m^2.

Temperature of drying by currents of high and industrial frequency is regulated basically by capacity of inductor, frequency of alternating current, duration of stay of article in electrical field and magnitude of gap between inductor and article.

Regimes of artificial drying (time and temperature) are established depending upon varnish and paint materials and their color, since from the action of high temperatures it is possible to change color and lustre of film coating.

Approximate norms of expenditure of operating mixtures in g/m^2 of painted surfaces are given in Table 24.

A list of control operations is in Table 25.

<u>Organization of painting.</u> Depending upon given technology of manufacture of part, its complexity, dimension, and also dimension of production article which maybe painted:

Table 24. Approximate Norms of Expenditure of Certain Varnish and Paint Materials in Painting Shops

Name of materials	Method of application	Expenditure operating of mixtures in g/m^2 per one layer
Operating of mixtures		
Priming on iron minimum	Brush	60-70
The same	Sprayer	90-100
Priming on zinc oxide.	Brush	100-120
The same	Sprayer	150-200
Priming of type 138	"	80-100
Spackling 1-st and 2-nd layers and first coat of type AM	Spatula	130-200
Nitrospackle type ASh-22, ASh-30, . . .	"	180-200
Clear oil varnishes	Sprayer	80-100
The same.	Brush	50-60
Oil and dark enamel varnishes	Sprayer	60-90
The same	Brush	35-60
Industrial enamels of various types . .	"	70-130
The same.	Sprayer	90-160
Nitroenamels of various colors	"	120-200
Nitroglyptal enamels	Sprayer 200-300	200-300
Perchlorovinyl enamels	"	150-200
Urea-formaldehyde enamel	Brush	100-130
	Sprayer	120-180
Diluents		
Various drying oils	-	Per instructions
Solvents (turpentine, white alcohol and others)	-	5-15% of weight of paint
The same for nitroenamels	-	100-120% of weight of enamel
White alcohol for degreasing surface . .	-	25-30
The same for grinding with sandpaper . .	-	40-50

Note: Materials shipped from manufacturers in the form of pigment pastes (oil paint and spackling) and in the form of ready mixtures (varnishes, enamels). Pigmental oil paint are diluted with drying oil. Up to the needed viscosity (working), materials are diluted additionally. Control of viscosity is done a funnel of NILK or a viscosimeter.

In assembled form; in accessible places are primed and painted before or in process of assembly;

In parts and assemblies; after final assembly, correction of defects (sometimes complete painting) and final finishing are carried out.

In complicated technology of parts and conditions of mass production painting operations can be done by several methods:

priming in shops, preliminary painting after machining and final painting of assemblies or assembled article.

Proceeding from volume of production and character of articles, operation of preparation, painting and finishing can be executed:

a) on continuous lines with continuous or periodic movement of articles on conveyers (mass production); equipment of passage type with input of articles at the one end and output from the other.

Operations of preparation, painting and drying can be carried out automatically during unification in one aggregate of part or the entire cycle. Hand operations (lubrication, grinding, finishing) are often executed outside the continuous line;

b) on continuous lines with periodic forward or forward-reverse movement of articles on carts or their own movement (series production). Equipment of passage or dead-end type;

c) at operating posts without movement of article (individual production of large articles), where operation of preparation, painting and finishing are carried out consecutively on one or several operating positions. Sometimes, for the purpose of reduction of cycle, equipment of the mobile type (mobile painting chambers and drying installations) is used.

For approximate calculation of painted surface it is possible to use the following empirical formulas:

Surface of stamped articles form sheet metal

$$\Phi = \frac{2A}{B\gamma}\ m^2 \text{ for, steel } \Phi = \frac{1.1A}{4B}\ m^2.$$

Surface of articles from rod or wire

$$\Phi = \frac{4A}{D\gamma}\ m^2; \text{ and for steel } \Phi = \frac{1.1A}{2D}\ m^2,$$

where A — weight of articles in kg; B — average thickness in mm; D — average diameter in mm; γ — specific gravity.

Table 25. Control of Coating Quality*

No. of OST, GOST	Index of quality	Content of control operation	Equipment and tools
OST 10086-39 M. I. 19	Color and shade of covering	Comparison of color and shade of painted plate with standard	Glass or steel plates 100 × 30 mm. Painting standards
GOST 5233-50	Hardness (abstract number)	Determination of relation of time of damping of oscillations of pendulum, supported on plate with applied covering, to time of damping of them on standard (glass) plate	Pendular instrument M-3, stop watch, glass plates of dimension 9 × 12
GOST 4765-49	Durability (impact) in kg/cm	Determination of maximum height of drop on painted plastic with weight of 1 kg, at which coating is not broken	Instrument U-1A, steel or duralumin plates
GOST 6806-53	Flexibility (elasticity) in mm	Definition smallest diameter of rod, during bend on which mechanical destruction of the plastic with covering does not occur	Plate from iron or aluminum with thickness of 0.2-0.3 mm., instrument ShG (scale of flexibility, (4×)
OST 10086-39 M. I. 31	Water resistance in hr	Determination of ability of covering to sustain action of water. Beginning of destruction of covering and its peeling is noted	Plate from iron. Glass bath
OST 10086-39 M. I. 33	Stability to acids, alkalis and other reagents in hr	Determination of ability of covering to sustain action of different reagents. Beginning of destruction of covering (loss of luster, appearance of discolorations, bubbles, peeling etc.) is noted	Metallic rods with diameter of 10-11 mm. Glass bath
Technical conditions for varnish and paint materials	Gasoline and, oil resistance in hr	The same. In case of need, check mechanical properties of covering for hardness, durability and flexibility	Plate from iron or aluminum, instruments M-3, U-1A, ShG
The same	Heat resistance in hr	The same, after endurance of covering during the given time at increased temperature	Plate from iron or aluminum. Instruments M-3, U-1A, ShG drying cabinet with regulated temperature
GOST 6992-60	Atmospheric stability in months	Determination of following changes of covering: loss of gloss, change of color, appearance of grid, baring of primer (airing), peeling of covering, appearance of chalking, corrosion etc.	Hood station, shields for test; for accelerated (comparative) tests of plate with covering, apparatus of artificial weather IP-1-2
Technical conditions for varnish and paint materials	Corrosion stability in hr	Determination of time to start of destruction of covering under action of corroding solution (usually 8-10% solution of table salt)	Plates with applied covering. Corrosion chamber

*It is done by laboratory means on plates with covering, applied preliminarily in laboratory or simultaneously with painting of article. In case of need-control of quality of varnish and paint coverings is done in process of operational tests with a test sample of the part.

Surface of large metallic constructions $\Phi = (12.5\text{-}15)A\ m^2$, where A — weight of construction in tons.

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